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ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL

FISCAL YEAR 1943

BY

A. C. FIELDNER, J. C. BELTZ, AND P. L. FISHER

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL FISCAL YEAR 1943[1]

By A. C. Fieldner,[2] J. C. Beltz,[3] and P. L. Fisher[4]

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[1] The Bureau of Mines will welcome reprinting of this paper, provided the following acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7272."

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INTRODUCTION

All technical facilities of the Bureau of Mines have been geared for more efficient use and conservation of mining equipment, developing plans for safety, improving the quality of coal through better methods of preparation, studying the problems of coal storage and utilization, and extending the uses of coal[5] for the war and postwar economy. The Bureau is now analyzing all of the coal purchased by the Army and much of that required by the Navy. Work on boiler feed water was doubled over last year to meet the increased demand made by the War Department for protecting vital boiler plants in many new camps and defense plants. Progress has been made in safely storing coal to reduce dangers of spontaneous ignition to a minimum and to preserve coking power. Mixtures of oil and coal to be used as a substitute fuel have been investigated. Technical service on the conversion of plants to other fuels has been given to government agencies and private consumers. The possibilities of making motor fuel, synthetic rubber, plastics, and other chemical products from coal have received greater attention because of the shortages of these vital commodities and the raw materials from which they are made. It is expected that both petroleum and coal may be called upon to provide primary chemical products in addition to the byproducts now produced in gas and coke-oven plants. The hydrogenation of coal offers a scheme for primary conversion of coal to liquid and gaseous products. War demands for coke have resulted in the discovery of additional reserves of western coals with good coking properties or suitable for blending with other coals for making blast-furnace coke. Improvements in the quality of metallurgical coals by reducing impurities or controlling the variation in impurities have yielded better coke and prevented loss of output from blast furnaces.

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[5] Ickes, Harold L., Coal's New Horizons: Coal Age, vol. 48, No. 4, April 1943, pp. 54-64.

A Fuel Efficiency Campaign has been organized with the cooperation of business and industry, municipal officials, trade and manufacturing associations, engineering societies, real estate boards, publishers, and other interested groups to effect savings in fuel required by government, industry, and private consumers. Because of the scarcity of petroleum coke, the Bureau developed a method of producing, from certain low-ash coals, electrode carbon used in the production of aluminum. In the annual report for fiscal year 1942,[6] the stimulus of modern warfare on coal research is clearly indicated, and many of the new developments will have important peacetime applications.[7] The present report is the eighth in a series of annual reports describing the progress of research and technologic investigations on coal during the fiscal year 1943. References are given to the publications of the Bureau that report more completely on these investigations. Much of the Bureau's work is now confidential, and details cannot be disclosed during the national emergency. Reports covering these studies will be available after the war, and they will form a valuable source of information for the development of new uses for coal and its products.

ACKNOWLEDGMENTS

This report includes work done under the technical direction of the following members of the staff of the Bureau of Mines:

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[6] Fieldner, A. C., and Rice, W. E., Annual Report of Research and Technologic Work on Coal, Fiscal Year 1942: Bureau of Mines Inf. Circ 7241, 1943, 63 pp.

[7] Fieldner, A. C., Coal Developments in Washington, D. C.: Proc., Firs Fuel Eng. Conf. of Coal Bur., Upper Monongahela Valley Assoc., Morgantown, W. Va., July 1942, pp. 35-37. Also, as Rubber from Coal: Coal-Heat, vol. 43, No. 1, Jan. 1943, p. 43.

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Oklahoma Geological Survey.
University of North Dakota.
University of Washington.

PROPERTIES AND COMPOSITION OF AMERICAN COALS

Inspection, Sampling, and Analysis

At the request of the War Department, the Bureau of Mines inspected and sampled coal purchased by that department for the purpose of effecting a saving in original cost of coal by more careful and reliable inspection and sampling and in operation of burning equipment by obtaining coal suitable for such equipment. A similar service was rendered to other Federal agencies. The analyses of these samples were made available to the publi through public files and publications. Assistance was given to finding coal suitable for making coke for metallurgical use in new war industries, and samples were obtained for carbonization tests and to determine suitability of low-ash coal for use in making carbon electrodes. Coal purchases by Federal agencies increased from approximately 3,500,000 tons before the war to approximately 11,500,000 tons during the fiscal year 1943, the greater part of the increase being for the War and Navy Departments. Three sampling trucks were operated continuously and a fourth truck for 5 months to obtain samples for analyses for use in awarding contracts for supplying coal to the Government. This work assumed special

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significance during 1943. These trucks obtained samples from 490 mines in 18 States, where 1,520 samples of bituminous coal were prepared - 36 from Arkansas, 4 from Idaho, 62 from Illinois, 17 from Indiana, 89 from Iowa, 24 from Kansas, 62 from Kentucky, 49 from Missouri, 80 from Montana, 76 from North Dakota, 29 from Ohio, 268 from Oklahoma, 5 from Oregon, 41 from Pennsylvania, 4 from South Dakota, 132 from Washington, 530 from West Virginia, and 12 from Wyoming.

In connection with the inspection of purchased coal, the Coal Analysis Laboratory reported analyses of 9,822 samples representing approximately 4.3 million tons of coal. In addition, 2,523 samples were analyzed for correlation with research of the Bureau on the utilization of coal by carbonization, combustion, gasification, and hydrogenation, in connection with methods of mining and sampling of drill cores, and the preparation of coal for oil-coal mixtures.

Federal coal-mine inspectors submitted 10,401 samples collected in inspections conducted to increase safety and establish healthful conditions in coal mines. These samples consisted of coal and rock dust in varying ratios taken from roads, ribs, and roofs of mines. Limits of safety for combustible material in mine dust were determined in addition to the usual analyses of these samples.

Analysis and Testing of Coal in Relation to its Properties and Utilization

An address by A. C. Fieldner[8] was presented by sound film at the awarding of the Melchett medal by the Institute of Fuel of Great Britain. The author reviewed the contributions of the Bureau of Mines over a period of 35 years, to the development and improvement of testing methods, and their application to the evaluation of those properties of coal that are important in its preparation and use, either directly as a fuel or for the production of gas, coke, liquid fuel, or chemical products.

Analyses of Pennsylvania Bituminous Coals

A new volume[9] contains analyses of many bituminous coals mined in Pennsylvania from July 1, 1937, to June 30, 1941. This supplements

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[8] Fieldner, A. C., The Analysis and Testing of Coal in Relation to its Properties and Utilization: Jour. Inst. of Fuel, vol. 16, No. 86, Oct. 1942, pp. 4-20. Also, Fuel in Sci. and Prac., vol. 21, No. 6, Nov. - Dec. 1942, pp. 118-128, and vol. 22, No. 1, Jan.-Feb. 1943, pp. 4-12.

[9] Snyder, N. H., and Swingle, R. J., Analyses of Pennsylvania Bituminous Coals: Bureau of Mines Tech. Paper 645, 1942, 19 pp.

Bureau of Mines Technical Paper 590 (1939, 503 pp.), which contains earlier analyses and chapters on the geology of the coal fields, methods of mining and preparation, and statistics on production, distribution, and use. Individual or average analyses are given according to the sources of samples.

Analyses of Illinois Coals

A compilation[10/] of analyses of Illinois coals from the Bureau of Mines files is presented in this paper, another in the series of publications that describe the coals of individual producing States. The surface and structural features of the Illinois coal basin, methods of mining and prepar tion, and the economics of production, distribution, and uses are discussed. Descriptions of samples from the mines include chemical analyses, calorific values, fusibility of ash, classification of coal by rank, thickness of beds, nature of floor and roof, and partings in the beds. Illinois ranked third in coal production in the United States in the seven years 1933 to 1939, and the original reserves of coal in the State have been estimated to be 201 billion net tons.

Typical Analyses of Coals of the United States

The Bureau of Mines has accumulated a comprehensive file of coal analyses on virtually every coal field of commercial importance in the United States. As knowledge of the composition of coal is potentially valuable to every user of coal, the Bureau publishes its analytical records. Many inquiries are received each year as to the composition of coals obtained from specific localities or, conversely, as to the localities from which a given type of coal may be obtained. The properties of commercia coal resources of the country have been summarized in tabular form.[11/] Specimen analyses are given exemplifying the analysis of coal mined in each coal-producing county, or, where it was feasible, coal from each bed in the county. In addition, where enough analyses are available, rang are given within which the composition of most of the coals represented will fall.

[10/] Fieldner, A. C., Cady, G. H., Toenges, A. L., Maize, E. R., Fraser, Anderson, R. L., McBride, J. W., Snyder, N. H., Cooper, H. M., Abernethy, R. F., Tarpley, E. C., and Swingle, R. J., Analyses of Illinois Coals: Bureau of Mines Tech. Paper 641, 1942, 245 pp.

[11/] Fieldner, A. C., Rice, W. E., and Moran, H. E., Typical Analyses of Coals of the United States: Bureau of Mines Tech. Paper 446, 1942, 45 pp.

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Moisture Losses in Sampling Coal

Moisture content of coal is transient, depending on several factors: The moisture normally present in the coal as it is found in the mine, procedures employed in cleaning, weather conditions, distance of shipment, and rank and size of the coal. In an investigation conducted jointly by the Fuel Inspection and Coal Analysis Sections of the Bureau for the American Society for Testing Materials, the loss of moisture in the tipple-sampling procedure as employed by the Bureau of Mines, averaged 0.15 percent, which is less than the tolerance allowed for moisture determination in the laboratory.[12] Repeatedly passing high-moisture coal through the crusher results in slight differences between consecutive crushings, and size distribution of the pulverized coal after the third or fourth crushing permits riffling down to the 3-pound sample that is forwarded to the laboratory for analysis. If properly protected from moisture changes, the mine sample may be taken to the surface for pulverization in mechanical crushers.

Properties of Coal

Chemical and Physical Properties of Colorado Subbituminous Slack

Approximately 1,250,000 tons of 2-1/2-inch and 1-1/2-inch slack are produced in the Denver, Colo., region each year by crushing lump coal and rescreening coal to make pea and modified-pea sizes for consumption in industrial plants. The increasing production of hydroelectric power has reduced the consumption of coal at power plants only slightly. There is indication, however, that with a still greater increase of hydropower, the trend of consumption of slack might be downward. At the same time, the rapid increase in number of domestic stokers has necessitated preparation of greater quantities of stoker coal, with the result that more lump is crushed, and preparation practices have had to be adapted accordingly. The quantity crushed has increased 12 percent during the last 6 years. The trend toward the use of clean and smaller sizes for domestic stokers gives a slack having a larger proportion of fines, and some use will have to be developed for the greater quantities of small slack. The possible future distribution of sizes, uses, and price differentials of this coal have been estimated.[13] The chemical and physical properties of both natural and crushed slack coal have been studied. As the subbituminous coals do not coke or change in shape when burned, it is important to know the sizes of coal fed to a burner to improve combustion efficiency and permit equipment to be designed that will burn these fuels automatically. It was found that about half of the 2-1/2-inch slack can be prepared as small sizes best suited for domestic stokers. Performance trials on domestic stokers revealed that 1/4- by 1-inch subbituminous coal is best for use in domestic stokers, as this size produces less fly ash and more unifor fuel beds, owing to minimum degradation in the stoker worm. If 1/8-inch dust can be removed from stoker sizes, a greater yield of suitable domesti stoker fuel (about 53 percent) can be obtained from 2-1/2-inch slack.

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[12] Cooper, H. M., Snyder, N. H., and Abernethy, R. F., Moisture Losses in Sampling of Coal: Bureau of Mines Rept. of Investigations 3670, 1942, 14 pp.

COAL MINING

Experimental Coal Mine

Decay of Mine Timber

The support of the roof in coal mines is essential for safe operation, and timber is the most common means of support. Its effectiveness depends upon its resistance to decay. The theory has been advanced by some mine operators that rock dust, which is applied to coal-mine workings to prevent propagation of explosions, accelerates the decay of mine timbers. The principal objectives of this study were to determine the effect of rock dusting upon decay of mine timber, to compare the extent of decay of timbe in two mines in which underground conditions were similar, and to determ the loss in strength of the timbers after exposure to mine atmosphere. Th investigation[14] was carried on in the Crucible mine of the Crucible Fuel and in the Isabella mine of the Weirton Coal Co. The effect of rock dustin upon average specific gravity and crushing strength of oak, hickory, and maple timber is shown graphically in figures 1 to 12, inclusive. Figures 7 to 12, inclusive, show the relation of percentage loss in specific gravity and crushing strength of these specimens to time of exposure. The result of this study indicate (1) that rock dust does not contribute to the decay of

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[13] Parry, V. F., and Landers, W. S., Size Consist, Chemical Analysis, and Physical Properties of 2-1/2-inch Subbituminous Slack from the Denver (Colo.) Region: Bureau of Mines Rept. of Investigations 365 1942, 30 pp. Also, Proc., Rocky Mt. Coal Min. Inst., 1942, pp. 69-7

[14] Scudder, J. N., Dekay, H. E., Jr., and Toenges, A. L., A Study of Deca of Mine Timber, Part 2: Bureau of Mines Rept. of Investigations 3710, 1943, 14 pp.

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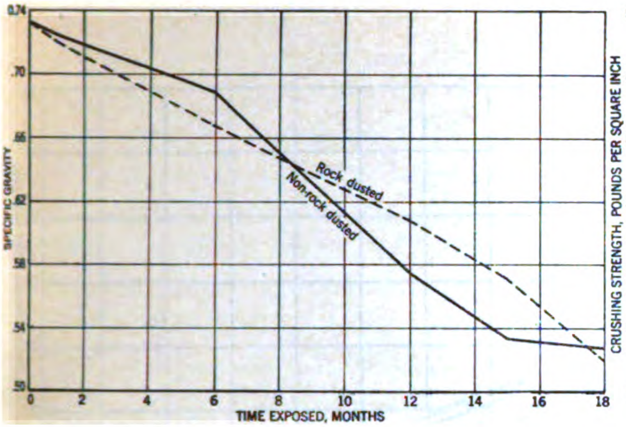

Figure 1.- Relation average specific gravity of oak, hickory, and maple specimens to time of exposure in Crucible mine.

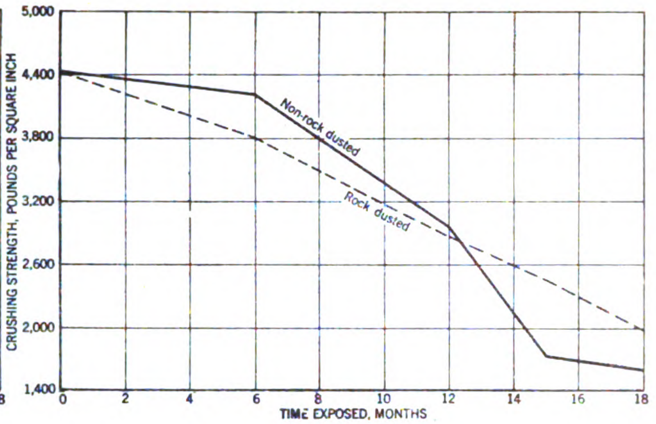

Figure 2.- Relation average crushing strength of oak, hickory, and maple specimens to time of exposure in Crucible mine.

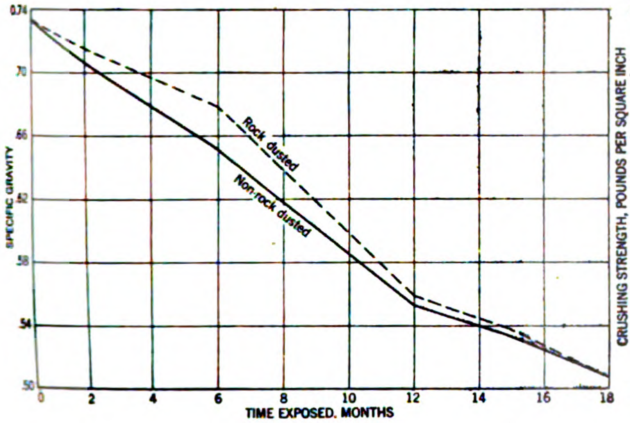

Figure 3.- Relation average specific gravity of oak, hickory, and maple specimens to time of exposure in Isabella mine.

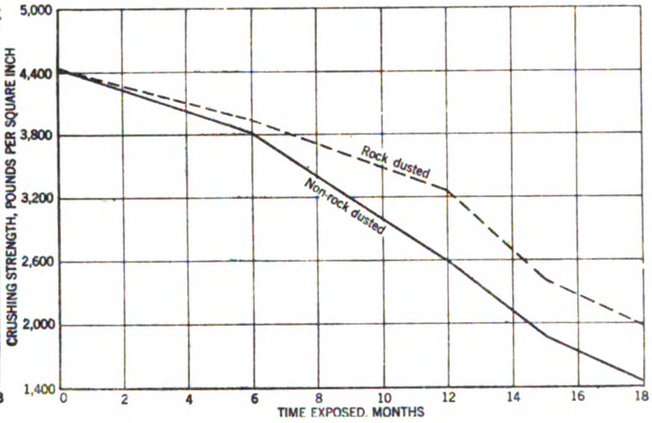

Figure 4.- Relation average crushing strength of oak, hickory, and maple specimens to time of exposure in Isabella mine.

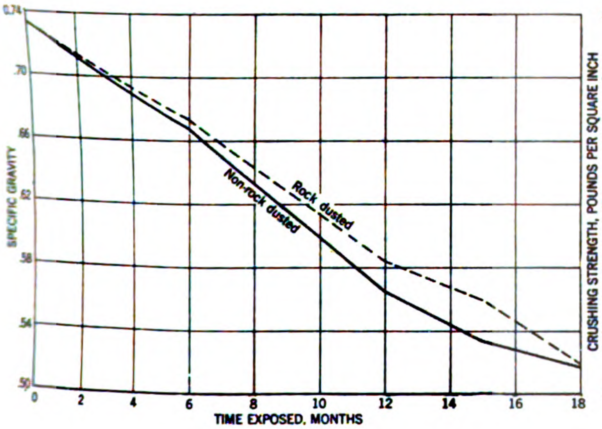

Figure 5.- Relation average specific gravity of oak, hickory, and maple specimens to time of exposure in Crucible and Isabella mines.

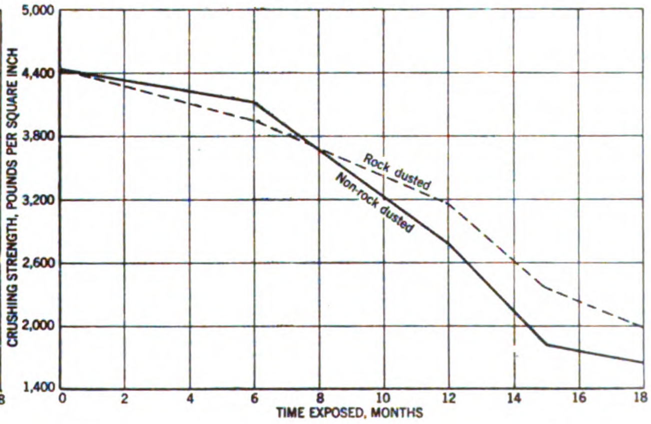

Figure 6.- Relation average crushing strength of oak, hickory, and maple specimens to time of exposure in Crucible and Isabella mines.

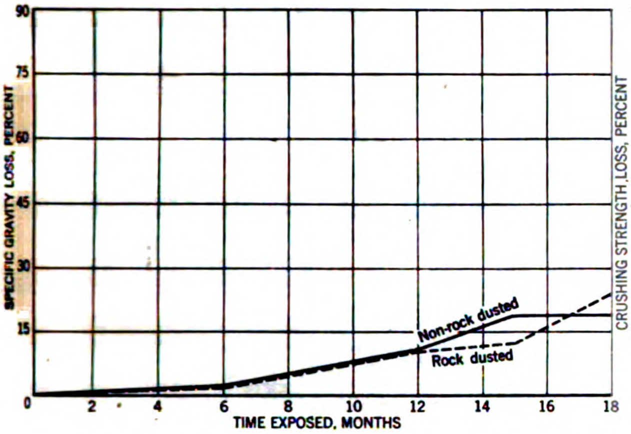

Figure 7.- Relation average percentage specific gravity loss of oak specimens to time of exposure in Crucible and Isabella mines.

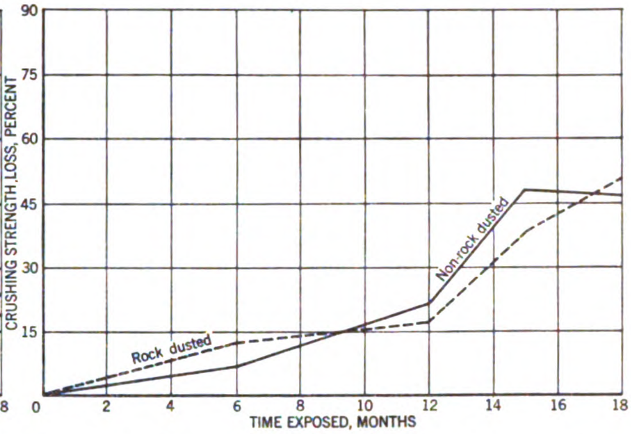

Figure 8.- Relation average percentage crushing-strength loss of oak specimens to time of exposure in Crucible and Isabella mines.

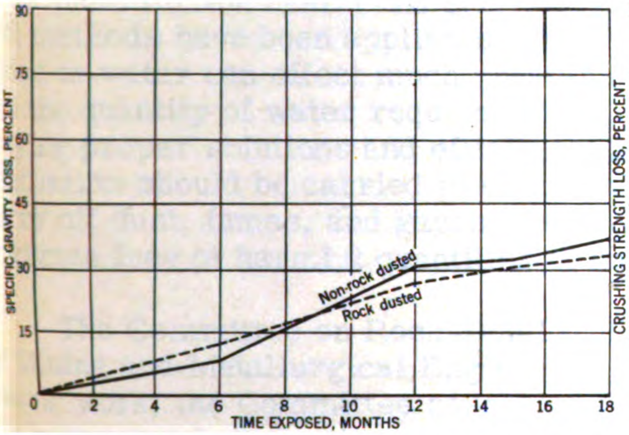

Figure 9.- Relation average percentage specific gravity loss of hickory specimens to time of exposure in Crucible and Isabella mines.

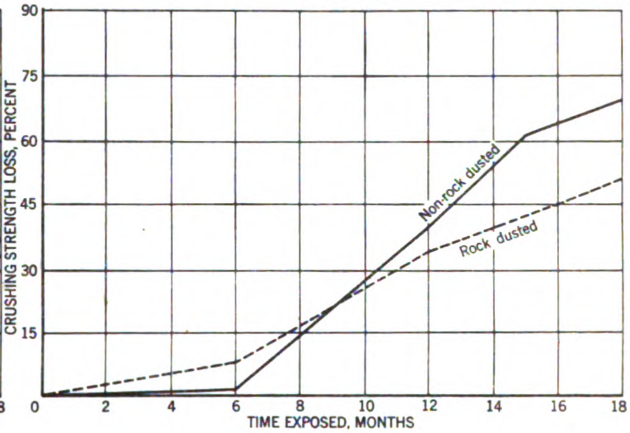

Figure 10.- Relation average percentage crushing-strength loss of hickory specimens to time of exposure in Crucible and Isabella mines.

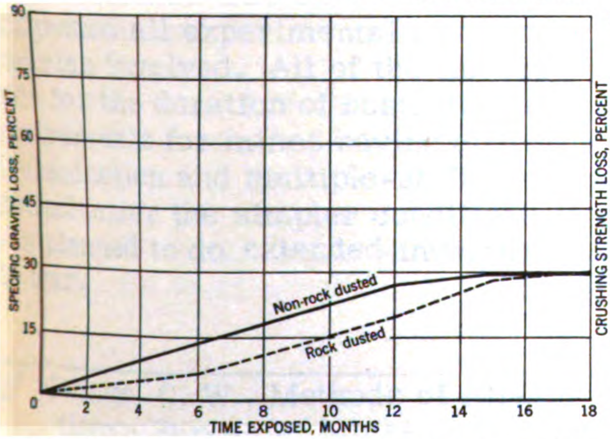

Figure 11.- Relation average percentage specific gravity loss of maple specimens to time of exposure in Crucible and Isabella mines.

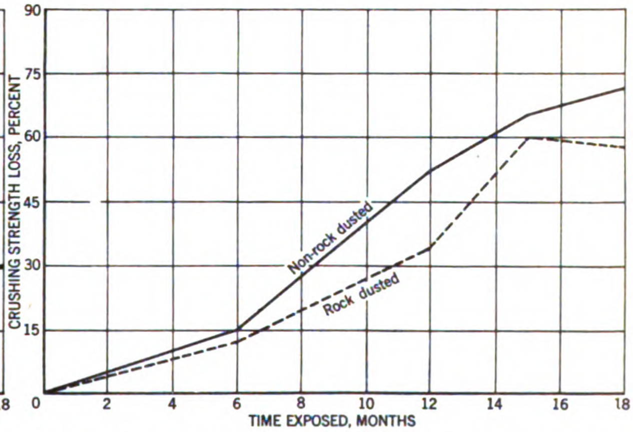

Figure 12.- Relation average percentage crushing-strength loss of maple specimens to time of exposure in Crucible and Isabella mines.

timber in the two mines studied; (2) upon comparison, the average percentage losses in specific gravity and crushing strength of rock-dusted and non-rock-dusted specimens of all species in the Crucible mine were found to be 2 percent less than those in the Isabella mine, and (3) loss in crushing strength of the test timbers after 18-months' exposure in mine atmosphere ranged from 40 to 54 percent for oak, 54 to 75 percent for hickory, 57 to 73 percent for maple, and not more than 21 percent for locust.

Dust in Underground Mining Operations

The mining industry in the United States is becoming fully cognizant of the hazards of explosive or combustible dust in underground mining as well as in surface plants. In coal mining the dust-explosion hazard has increased as a result of the rapid growth of mechanized mining. Methods for allaying dust in mining operations have been studied and recommendations made for the health and safety of men employed in the industry.15/ Wet methods have been applied successfully in coal mines. Wetting agents added to water can effect much greater reduction in dust than water alone, and the quantity of water required may be reduced to less than half by employing proper solutions and efficiently designed nozzles. Adequate positive ventilation should be carried to each working place with enough velocity to carry off dust, fumes, and gases at a rate that will keep the air breathed by workmen free of harmful quantities of dust and gases.

The Committee on Rock-Dusting, Coal Division, American Institute of Mining and Metallurgical Engineers, was formed in 1938. After two years' work, the Committee concluded that although certain portions of the recommended practice could well be revised, information needed for a logical revision was not at hand, and it was inadvisable, therefore, to make revisions. The advent of the war in Europe quickly relegated to the background all experimental work having to do with rock-dusting in the countries involved. All of the Bureau's work along this line has been laid aside for the duration of hostilities.16/ Questions are arising concerning requirements for mines having operating conditions out of the ordinary. Mechanization and multiple-shift working pose rock-dusting problems not present under the simpler conditions of hand loading and singleshift work. It is planned to do extended investigational and experimental work after the war.

15/ Owings, C. W., Methods of Allaying Dust in Underground Mining Operations: Bureau of Mines Rept. of Investigations 3631, 1942, 38 pp.

16/ Greenwald, H. P., Progress in Rock-Dusting Investigations Halted for the Duration of the War: Min. and Met., Feb. 1943, pp. 78-79.

Multiple-Shift Mechanical Mining

Extraction of Pillars with Mechanized Equipment

The extraction of coal pillars with mechanized equipment to increase the percentage of recovery presents many problems.[17] Investigations made in some bituminous-coal mines suggest answers to certain inquiries: 1. Why has the percentage of recovery of coal from an area decreased in some mines and increased in others when a change has been made from hand to mechanical loading? 2. Can the method of extracting pillars by hand be adapted to machine loading? 3. Are fewer tons produced per unit in mines where pillars are extracted? 4. Does extraction of pillars by machines introduce additional hazards?

A common error in equipping mines for mechanical loading is failure to study natural conditions and to choose the type of equipment suited to them. In many instances mine design or method of extraction was not changed. Introduction of loading equipment, especially mobile loading machines, usually requires some such change, particularly if the roof is fragile. Where no thought has been given this problem, small pillars and stumps that normally were removed by hand-loading methods, using close timbering, have been lost, and recovery has declined. Credit should be given to those operators who first tried the various types of equipment and passed on their experience. Transition was successful usually after considerable study of bed and roof conditions.

No positive statement can be made relative to the adaptability to mechanical loading of the method of extracting pillars by hand. Hand-loading methods usually are unsuited for mechanical loading devices, particularly loading machines. The most successful hand-mining method for pillar removal is the pocket-and-wing in rectangular blocks. Close timbering is required to recover the wing. This system has not been successful with mechanical-loading devices because the area is restricted by timberin Pillar extraction with mechanical devices, however, has been successful with the open-end or thin-shell systems, because the rate of extraction is rapid. The time element in hand-loading does not favor the open-end method. Past experience indicates that less tonnage per day per mobile loading machine is produced on pillar work than when pillars are not recovered. The opposite is usually true where conveyors or scrapers are used.

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[17] Toenges, A. L., Maize, E. R., and Jones, F. A., Multiple-shift Mechan cal Mining in Some Bituminous Coal Mines. Progress Report 4. Extraction of Pillars with Mechanized Equipment: Bureau of Mines Inf Circ. 7223, 1942, 59 pp. Abstracted in Min. Cong. Jour., May, 1943, pp. 50-53.

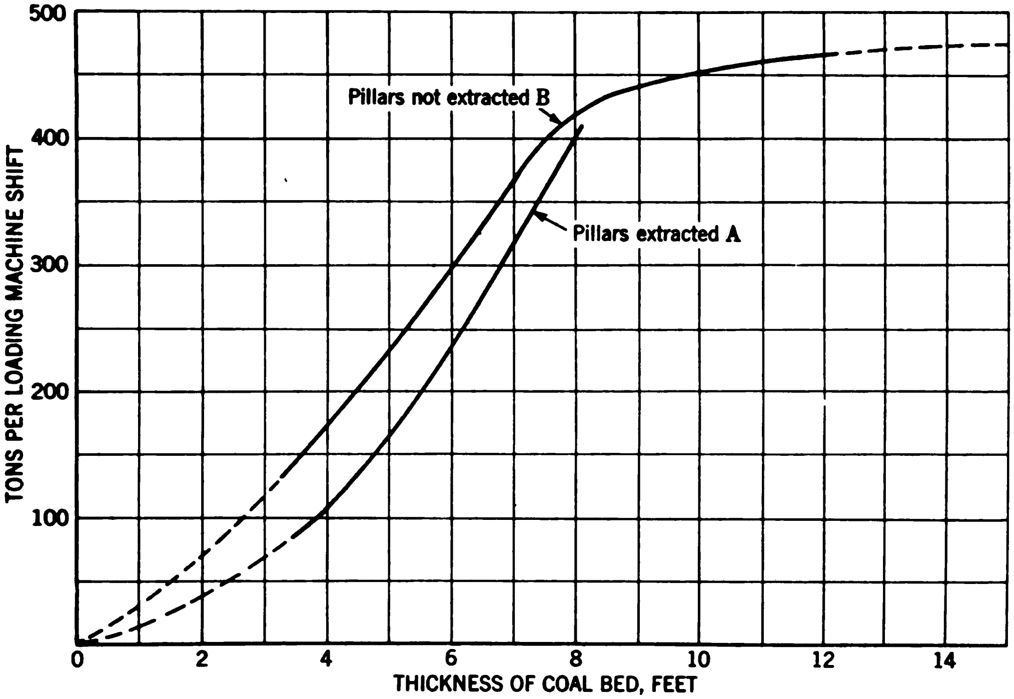

Figure 13.- Relation of thickness of bed to tons per loading-machine shift.

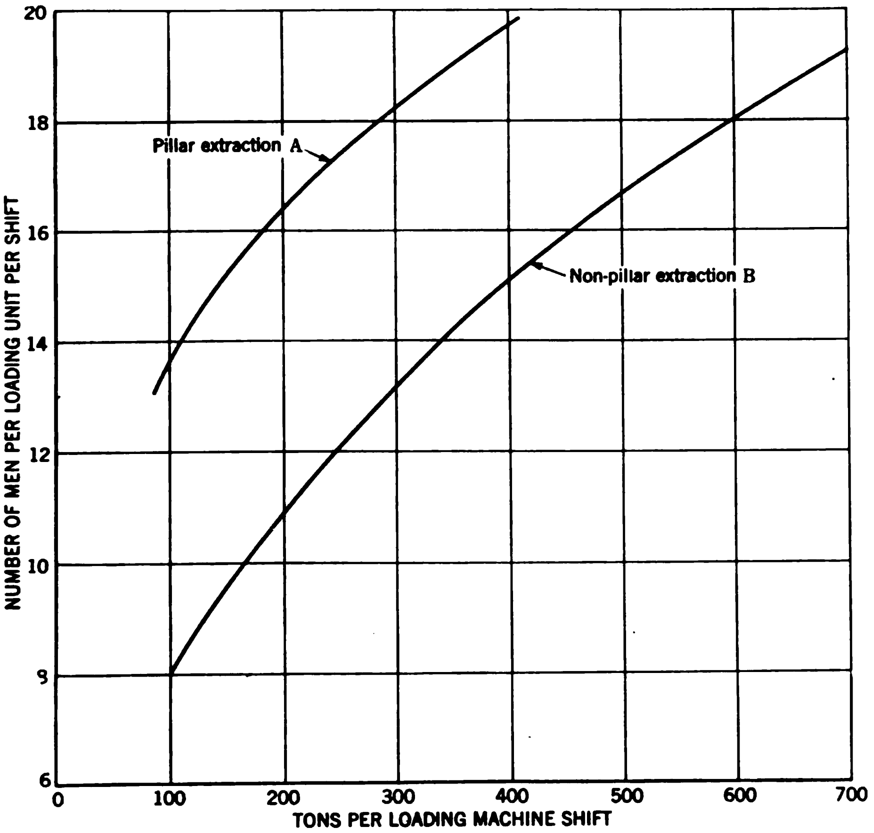

Figure 14.- Relation of number of men per loading-machine unit per shift to tons per loading-machine shift.

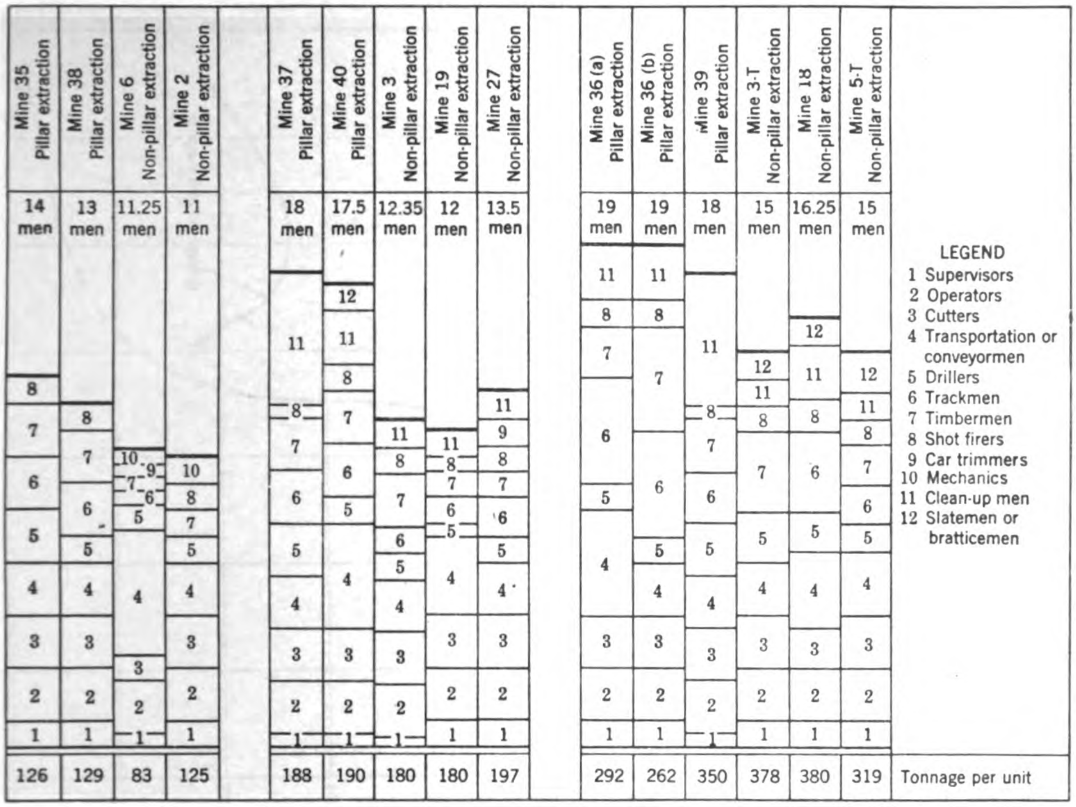

Figure 15.- Occupational distribution of loading crewmen.

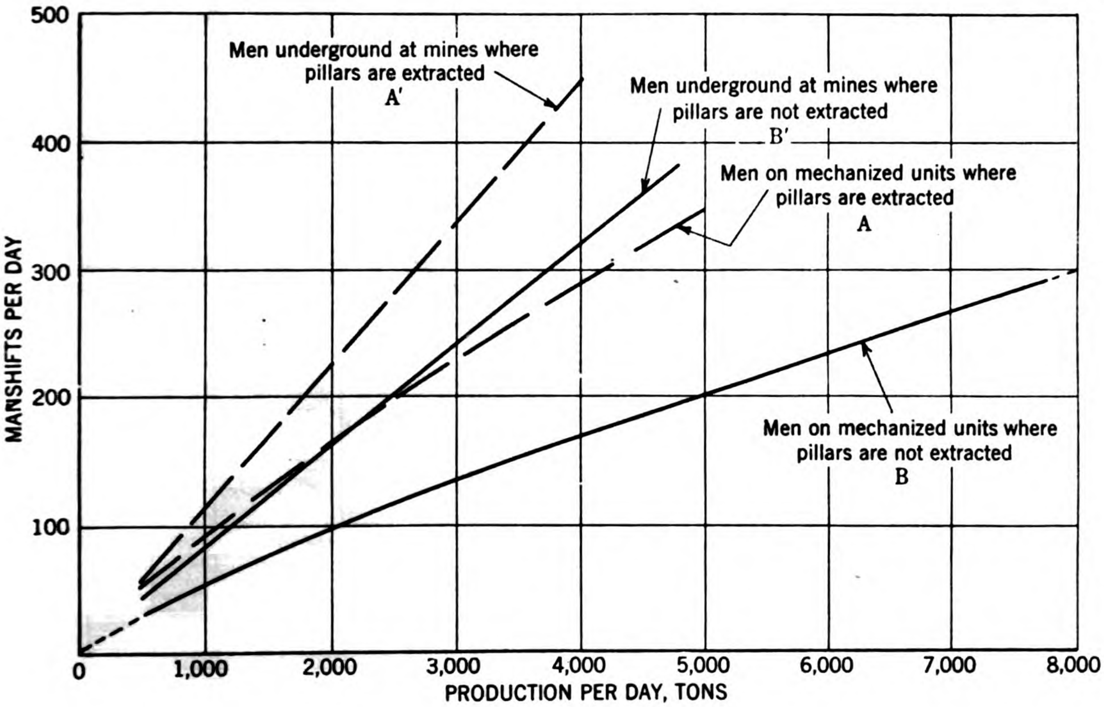

Figure 16.- Relation of manshifts per day to production per day, mobile loading machine.

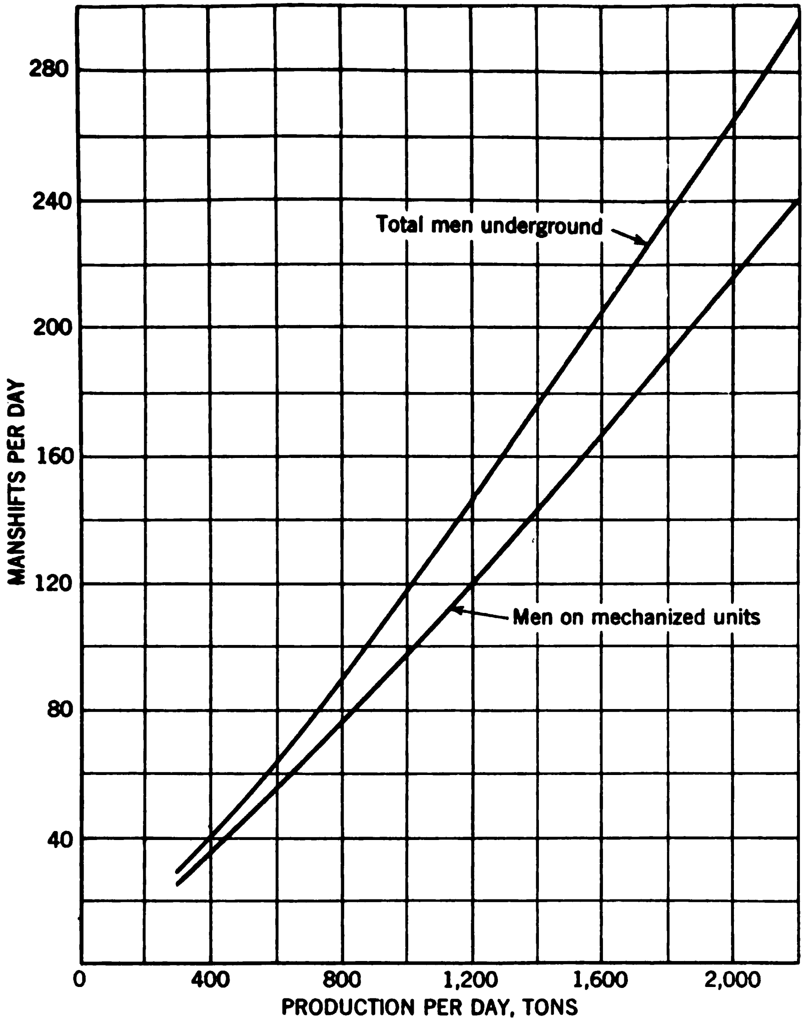

Figure 17.- Relation of manshifts to production per day, conveyors.

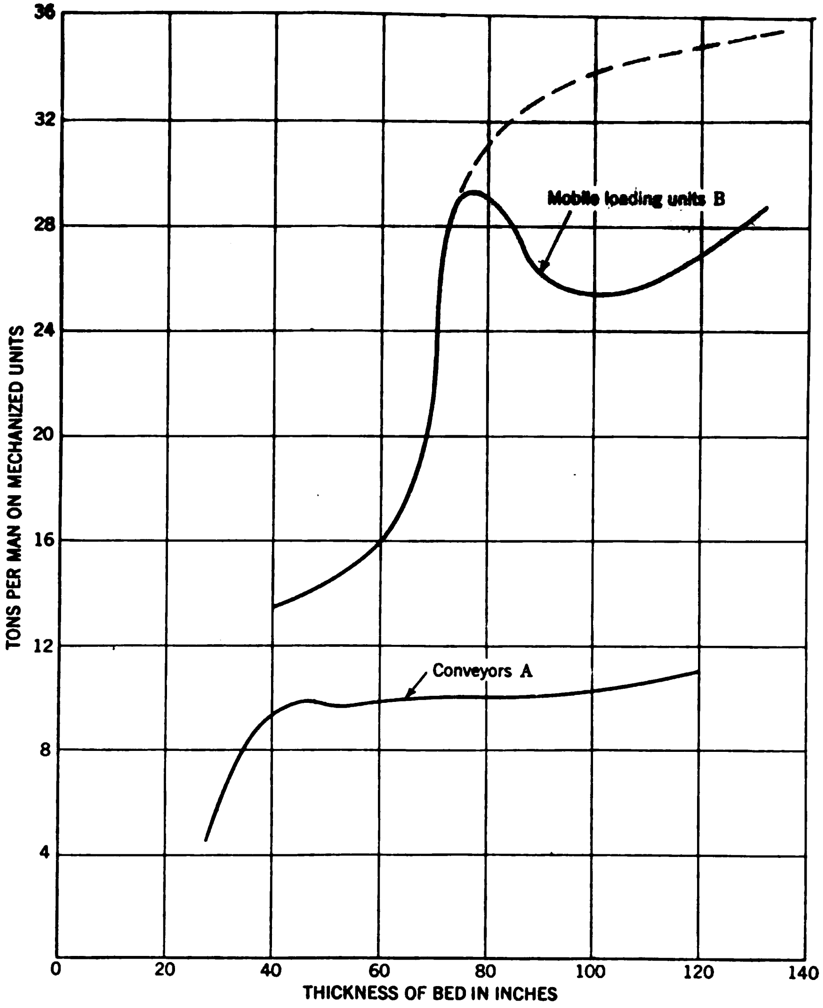

Figure 18.- Relation of bed thickness to tons per man on mechanized unit.

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Additional hazards are introduced by extraction of pillars with machines. Motion and noise of machines and transporting equipment and, in some instances, the liberation of additional gas due to rapid exposure of wall surfaces, are also dangerous. Conversely, many hazards are obviated or decreased where mechanical mining is practiced. Roof movement is delayed by rapid extraction; concentration of workers permits closer supervision, and ventilation can be controlled more readily. Data of various mines have been plotted in figures 13 to 18. The output from loading equipment can be increased materially if all operations in the mining cycle are properly coordinated. Adequate number and preparation of working places, minimum tramming distances and car changes are necessary to obtain maximum use of the loading equipment. A mining company's chief asset is coal in the ground. Development of a mine to extract only part of the bed is not only uneconomical but wasteful of a natural resource.

Haulage Safety Devices

The development of safety devices[18] for transportation equipment used in mines has not progressed with the requirements of the industry. There has been a general impression that it is not imperative to have safety devices on such conveyances. Attention must be given to providing those devices that will protect the workmen in mines. Devices applicable to grades and slopes include the various car stops, sprags, hooks, brakes, drags, and derail switches. On very steep slopes, the only satisfactory devices are those of the Klansnic type, Ady-type rail grips, or auxiliary cable grips such as the Prockter and Hardy-Tynes cars, and cams or safety dogs with guides. The only safety devices of known value for the steep gradients of inclined shafts are of the guide-and-cam type.

Handling Lubricants In and About Coal Mines

Recent Federal coal-mine inspections have revealed some good and some definitely hazardous practices and systems for transporting, handling, and storing lubricants in and about coal mines. Recommended practices[19] for mine operators and miners responsible for handling and using lubricants include the use of fireproof buildings, small spillproof containers, fire-protection equipment such as foam, carbon dioxide, or dry compound-type fire extinguishers, portable covered mine cars of fireproof construction, and extreme cleanliness in all lubricating operations.

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[18] Grove, G. W., Ash, S. H., and Ristedt, E. J., Some Haulage Safety Devices for Use on Grades, Slopes, and Inclined Shafts: Bureau of Mines Miner's Circ. 43, 1942, 44 pp.

[19] Kingery, D. S., Some Information on the Transportation, Storage, and Handling of Lubricants In and About Coal Mines: Bureau of Mines Inf. Circ. 7244, 1943, 7 pp.

Mechanization - What Is It?

In a series of articles, of which the fourth, fifth, and sixth appeared last year,[20] the application of simple machines to modern mining are discussed. The relationship between advances in civilization and the degre to which simple machines have evolved into the mechanical equipment now in use at many mines can be traced. In fact, most complicated machinery is a combination of simple machines. The composite unit is often so intricate that it is impossible to recognize the simplicity of its component parts

Use of Diesel Engines in Mines

Diesel Engines Underground

The principal events in one complete cycle of a 4-stroke-cycle Diese engine are (1) air intake on the suction stroke; (2) compression of air on the compression stroke; (3) fuel injection and initial combustion near the end of the compression stroke; (4) combustion and expansion on the expansion or power stroke, and (5) discharge of combustion products on the exhaust stroke. Improper functioning of the various auxiliary mechanisms and systems essential to each event will interfere with efficient operation of the engine and may significantly increase production of harmful and objectionable constituents of the exhaust. The effect on exhaust composition of variables that influence characteristics of fuel spray injected into cylinder of Diesel engines were investigated.[21] Tests showed that improperl operating valves can cause the concentration of carbon monoxide and aldehydes in the exhaust gas to increase significantly. Leaking valves offer t greatest potential hazard insofar as their effect upon the composition of t exhaust gases is concerned. Dirt in the fuel frequently causes trouble, an

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[20] Ilsley, L. C., Mechanization - What Is It? IV. - The Shadoof Crane: Mech., vol. 6, No. 7, July 1942, pp. 90-91.
Ilsley, L. C., Mechanization - What Is It? V. - The Archimedes Scr Mech., vol. 6, No. 8, Aug. 1942, p. 92.
Ilsley, L. C., Mechanization - What Is It? VI. - The Wheel and Axle Mech., vol. 6, No. 12, Dec. 1942, pp. 98-99.

[21] Holtz, J. C., Berger, L. B., Elliott, M. A., and Schrenk, H. H., Diesel Engines Underground. IV. - Effect on Composition of Exhaust Gas of Variables Influencing Fuel Injection: Bureau of Mines Rept. of Investigations 3700, 1943, 24 pp.

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every precaution should be observed to eliminate it from the fuel-injection pump and the injection valves. The atmosphere in which Diesel engines operate should be examined frequently to determine whether objectionable constituents of the exhaust are within permissible limits. Ventilation should be increased if results of such examination indicate that this is necessary to maintain safe and healthful conditions, but under no circumstances should the quantity of ventilating air be reduced below that estimated from tests made before the engine is placed underground. In connection with adequate ventilation, proper maintenance of the engine offers the logical safeguard against excessive concentrations of objectionable exhaust-gas constituents by controlling their production at the source.

In previous experiments, the toxic or objectionable gases determined were carbon monoxide, carbon dioxide, oxides of nitrogen, and aldehydes. Because of the low sulfur content of the fuels used in Diesel engines, compounds such as sulfur dioxide and sulfur trioxide were not determined. In subsequent tests,[22] a high-sulfur fuel (2.4 percent) was used to determine the effect of exhaust-gas composition on operation with a fuel of this type. Essentially all the sulfur in the fuel appeared in the exhaust gas as sulfur dioxide and sulfur trioxide. The ratio of these two gases varied - increasing temperatures of combustion increased the proportion of sulfur dioxide. No measurable increase was noted in the sulfur content of the engine-lubricating oil as a result of operation with the high-sulfur fuel during a limited test period. This statement confirms the results of exhaust-gas analysis, which showed that, with respect to exhaust-gas composition, all the sulfur in the fuel may be considered as appearing in the exhaust as sulfur gases. Comparable results were obtained with a fuel of low-sulfur content. It is concluded that the sulfur content of the fuel for Diesel engines should be limited to 0.3 to 0.4 percent, as otherwise ventilation requirements would have to be increased to dilute the sulfur gases in the exhaust to concentrations permissible in working environments.

Use of Diesel Locomotives in Tunnels

Another paper on the use of Diesel engines in mines,[23] written from the standpoint of the safety and health of the miners, indicates that adequate ventilation must be provided at all times to prevent physical damage or loss of life from the toxic gases generated. Observations of atmospheric conditions in tunnels where Diesel locomotives are in use indicated that the ratio of the concentration of nitrogen oxides to that of carbon monoxide is probably most often approximately 2.5:1, always more than 1:1 under load at any speed, and at times as high as 5:1. To provide satisfactory atmospheri conditions, at least 65 to 75 cubic feet of fresh air must be supplied per minute per brake-horsepower developed at maximum rated speed and maximum load by a Diesel engine when operating in normal air. Experience ha demonstrated that acceptable conditions are attainable in the general tunne air when the carbon monoxide concentration is kept within the range 0.001 to 0.002 percent by volume and is used as a yardstick for the control of atmospheric conditions.

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[22] Berger, L. B., Elliott, M. A., Holtz, J. C., and Schrenk, H. H., Diesel Engines Underground. V. - Effect of Sulfur Content of Fuel on Composition of Exhaust Gas: Bureau of Mines Rept. of Investigations 3713, 1943, 13 pp.

[23] Ash, S. H., and Naus, L. L., Use of Diesel Locomotives in Tunnels: Bureau of Mines Inf. Circ. 7222, 1942, 26 pp.

Combustion in Diesel Engines

In a study of the effects on exhaust-gas composition of adding natura gas to the intake air of commercial Diesel engines,[24] results were obtained that furnished considerable data on the mechanism of combustion in the Diesel engine and suggested the value of adding combustible gases to the intake as an experimental technique for studies in this field. Evidence is presented indicating the importance of an effect analogous to the lower limit of flammability in relation to combustion in the Diesel engine. The existence of overlean regions in which flame does not propagate is discussed, indicating that such regions probably are the source of carbon monoxide and aldehydes in the exhaust gas at fuel:air ratios lower than the chemically correct value.

Coal Production and Use of Energy in the Western States

A condensed summary of current statistics on production and use of various forms of energy in the Western States was made to determine the relative position of competing fuels and characteristics of western coal production.[25] The energy produced per capita was correlated with indexes of industrial activity, and a formula was derived to show the interdependence of each.

The actual amount of energy produced in the Western States is mor per capita than is produced in the United States as a whole. For 20 years

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[24] Elliott, M. A., and Berger, L. B., Combustion in Diesel Engines - Effect of Adding Gaseous Combustibles to the Intake Air: Ind. and Chem., vol. 34, 1942, pp. 1065-1071.

[25] Parry, V. F., Trends in the Use of Energy in the Western States (Wi Particular Reference to Coal): Bureau of Mines Rept. of Investigations 3680, 1943, 43 pp. Also, Proc., Rocky Mt. Coal Min. Inst., 19 pp. 30-65.

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the average production of energy in the Rocky Mountain area has been equal to 8.8 tons of coal per capita, or about 27 percent more than the average of the United States. About 84 percent of all the energy produced comes from oil, natural gas, and hydropower, whereas these forms of energy represent about 45 percent of total energy produced in the United States.

The variations in average quality of coal produced in different areas of the Rocky Mountain Region are tabulated, and fuel-utilization factors were calculated for the various fuels. Sources of coking coals in the Western States are listed by mining areas, and coals from these areas are classified by rank. The study includes a review of the status of carbonization and hydrogenation of coal in the Western States and gives data on the utilization of coal by railroads and characteristics of the coal-mining industry.

Analysis of the Use of Electricity in Coal Mines

An analysis of the use of energy and its distribution usually results in a saving in consumption of energy and a reduction of hazards.[26] The distribution system for electrical energy in coal mines should be designed to supply energy effectively and safely for efficient operation of all machines. The energy supplied to a section load center in a mine usually is distributed among five classes of equipment - cutting machines, loading machines, transportation units, drills, and pumps. The total maximum load for a section may occur only when the operations are simultaneous, but such an occurrence should be infrequent and of short duration. The conversion instrument must have sufficient capacity to equal the maximum load to insure uninterrupted operation. Section load probably can be reduced by coordinating operations, keeping track and roadways in good condition, preparing the face properly to provide broken coal for the loading machine and thus obviate digging of the face, not starting the cutting machines under load, and maintaining the cutting bar in a level position in top and bottom cuts and on vertical planes while shearing. The least energy was consumed in a section in which no bottom cuts were made. The highest consumption of energy per ton was recorded in a section where rubber-tired equipment was used. The largest consumer of energy is the main-line transportation system. The results of these studies should assist in reducing waste of badly needed power.

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[26] Jones, F. A., Thomas, E., Toenges, A. L., Maize, E. R., and Scudder, J. N., Analysis of the Use of Electricity at Coal Mines. Progress Report 2: Bureau of Mines Rept. of Investigations 3683, 1943, 25 pp.

Explosions and Use of Explosives in Coal Mines

To insure continued safety of permissible mining explosives, the Bureau made 149 chemical analyses, 967 gallery tests, and 2,148 control tests. There are now 180 explosives and 9 blasting devices (Cardox) on the active permissible list.[27] Changes in these listings from last year have been given in connection with the discussion of the work of the Explosives Division.[28]

Use of Sheaths Around Permissible Explosives

The use of sheaths or hollow cylinders of flame-extinctive materials surrounding cartridges of permissible explosives has been developed durin the past few years and has resulted in reducing further the ignition hazard that may cause many coal-mine disasters. A study of the effects of sheath on the gaseous products from explosives has been completed recently.[29]

In the Bichel gage, the use of sheaths for explosives with the least oxygen deficiency and the smallest weight-ratio of sheath to explosive resulted in greater volume of carbon monoxide; with increasing oxygen deficiency and increasing weight-ratio of sheath to explosive, a transition occurred until the use of sheaths was attended by decrease in volume of this gas. Only negligible amounts of oxides of nitrogen were produced, except for one explosive with the greatest oxygen deficiency and greatest weight-ratio of sheath to explosive. A somewhat greater total volume of gaseous products was obtained from sheathed explosives with the lower weight-ratios of sheath to explosive, whereas for the highest ratio there was a decided decrease in the total volume of gas; reductions in volume o hydrogen were marked with increasing oxygen deficiency and increasing weight-ratio of sheath to explosive. The use of sheaths led to great increa in the production of hydrocarbons and carbon dioxide.

In the Crawshaw-Jones apparatus, the use of sheaths generally increased the volume of carbon monoxide and hydrogen, but high weight-rat of sheath to explosive and high oxygen deficiency caused damping effects, in which volumes were obtained intermediate between the unsheathed shots at loadings of air-spaced and unit density. In general, very small quantities of oxides of nitrogen were obtained, irrespective of the loading. The total volume of gaseous products produced was greatest for the sheathed explosives, least for explosives loaded to unit density, and intermediate for air-spaced loading. The use of sheaths likewise increased the volume of hydrocarbons, the lowest values being obtained for the air-spaced loadings.

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[27] Tiffany, J. E., and Gaugler, Z. C., Active List of Permissible Explosives and Blasting Devices Approved Prior to June 30, 1942: Burea of Mines Rept. of Investigations 3665, 1942, 25 pp.

[28] Huff, W. J., Annual Report of the Explosives Division, Fiscal Year, 1942: Bureau of Mines Rept. of Investigations 3669, 1942, 43 pp.

[29] Murphy, E. J., Rowles, A. P., and Holtz, J. C., with Denues, A. R. T., Effects of Sheaths on Gaseous Products from Permissible Explosiv Bureau of Mines Rept. of Investigations 3705, 1943, 41 pp.

Apparently, sheaths introduced no important hazard in the production of carbon monoxide, but they may cause undesirable production of oxides of nitrogen under adverse conditions. Large quantities of water added to the sheath caused the production of copious quantities of these oxides in both series of tests.

Structural Features of Typical American Commercial Detonators

The developments of commercial American detonators during the past decade have been reviewed,30/ and the various types have been classified, according to their structure, into fuse detonators (designated also as blasting caps, fuse caps, fuse blasting caps, and ordinary blasting caps) and electric detonators (designated also as electric blasting caps and E. B. caps). Electric detonators may be either ordinary instantaneous, seismographic instantaneous, vented delay, or ventless delay. Numbers representing the strengths of various grades of detonators indicate how these compare with the strength of standard detonators that contain either 80:20 mercury fulminate-potassium chlorate, 90:10 mercury fulminate-potassium chlorate, or 100 percent mercury fulminate.

It is customary to define the initiating power of a detonator in terms of the test used. Thus, a No. 6 detonator may be defined as one not inferior in initiating power to a detonator containing 1 gram of a mixture of 80 percent mercury fulminate and 20 percent potassium chlorate. Four tests are employed to determine this strength: (1) TNT-iron oxide insensitive powder test; (2) sand test (also called sand-bomb test or sand-test bomb); (3) lead-plate test (the results of this test may be misleading as a measure of strength because the size of the hole produced is profoundly influenced by such factors as the shape and diameter of the bottom of the detonator and the nature of confinement of the explosive charge within the detonator), and (4) small Trauzl lead-block test.

30/ Grant, R. L., Structural Features of Typical American Commercial Detonators: Bureau of Mines Rept. of Investigations 3696, 1943, 30 pp.

Recent developments, accelerated by wartime scarcity of metals, indicate that synthetic plastics and resins may find use in future detonators. Detonator leg wires and leading wires insulated with extruded ethyl cellulose are being perfected and give promise that other plastics may find similar future application. Although a number of structural improvements in detonators for reducing the hazards from static electricity have been suggested, the peculiar origin and causes of static electricity under actual working conditions must be investigated further. Although no attempt has been made in the paper to describe foreign detonators, mention is made of British high-tension electric detonators. These differ from all American detonators in construction by having no bridgewire; instead, the conducting medium is the ignition material, which has a resistance of approximately 1,000 ohms and is fired by passing a high-tension current through it.

Approved Respiratory Protective Devices

One phase of the Bureau's work in health and safety has been the promotion of the use of safe, satisfactory, and reliable respiratory protective devices.[31] To insure that such devices will be available, the Burea has established schedules of minimum requirements for oxygen breathing apparatus, gas masks, supplied-air respirators (hose masks, air-line respirators, and abrasive blasting helmets, hoods, or masks), and dispersoid (dust, fume, and mist) respirators. The products of 18 companies have been approved.

Confining Cardox Blasting Devices in Boreholes

Cardox blasting is used widely in coal mines in the United States, with resultant certain special hazards. The increasing number of accident prompted a Bureau of Mines field investigation of possible methods of preventing dangerously violent ejections of Cardox devices.[32] As a result of this study, and in view of the 500,000 blasts said to have been fired by one company without a shell ejection with the sprag-pipe method of Cardox blasting, it is concluded that the method described is suitable for preventing the ejection of Cardox blasting devices under the conditions in the mines in which the tests were conducted. The sprag-pipe should be of chrome-molybdenum steel, or its equivalent, to resist the very violent ejections caused by mechanical failure; and it should be as nearly as possible of the same diameter and strength as the Cardox blasting device.

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[31] Schrenk, H. H., List of Respiratory Protective Devices Approved by t Bureau of Mines: Bureau of Mines Inf. Circ. 7237, 1943, 14 pp.

[32] Griffith, F. E., and Seeling, C. H., Some Information from an Investiga of Methods of Confining Cardox Blasting Devices in Boreholes in Ce tain Coal Mines: Bureau of Mines Rept. of Investigations 3714, June, 1943, 13 pp.

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A relatively shallow borehole is drilled at an angle across the mouth of the shot hole to be blasted. After the Cardox shell has been placed in position, a piece of 2-inch steel pipe 36 inches long is inserted to intersect and largely cover and obstruct the collar of the charged borehole. This pipe prevents ejection of the Cardox shell. In using this method, there should be no relaxation of the normal precautions taken to prevent injury to persons from ejected shells; the shot-firer should continue to see that all persons are in the clear, to be 100 feet or more from the blast, to be out of line of fire (around one or preferably two right-angle turns), and to give at least a third warning of intention to shoot before actually firing the blast.

Cushioned Blasting

Orienting tests in connection with cushioned blasting have shown marked effects upon practical hazards that affect the health and safety of miners and the efficiency of mining operations. Bureau of Mines investigations of cushioned blasting relate to the various means employed to reduce the intensity of application of energy from explosive actions in boreholes, and the division of this work corresponds to the salient hazards. These include the ignition hazard, hazards from poisonous gases, and other practical hazards in the blasting technique. The ignition hazard was resolved into two components of approximately equal weight. These include studies of effects upon the incendivity of blown-out shots and the occurrence of such shots. Experimental studies of effects upon the incendivity of blown-out shots were first undertaken, and results corroborate preliminary considerations that gallery testing can contribute significantly to estimates of practical effects in cushioned blasting upon the ignition hazards in coal mines.[33]

Detecting Organic Halide Gases in the Atmosphere

A simple tester for detecting low concentrations of halide gases in atmosphere has been developed.[34] The tester, based upon the principle of the well-known halide lamp, employs charcoal to adsorb and concentrate the halide-containing gases and thus greatly increases the sensitivity of the test. It is so constructed that tests may be made (1) by aspirating the suspected atmosphere through it, (2) by suspending it in the atmosphere, or (3) by swinging it in the atmosphere to be tested. Experiments were conducted on 25 different halide gases; results have proved that concentrations of less than 1 part per million of any of these gases in air can be detected by swinging the tester in the atmosphere for 30 seconds or longer, depending on the particular halide gas involved.

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[33] Denues, A. R. T., Cushioned Blasting. II. - Preliminary Studies of Gallery Testing: Bureau of Mines Rept. of Investigations 3674, 1943, 37 pp.

[34] Jones, G. W., and Kennedy, R. E., A Simple Device for Detecting Small Concentrations of Organic Halide Gases in the Atmosphere: Bureau of Mines Rept. of Investigations 3697, 1943, 10 pp.

Measurement of the Minimum Electric Spark Igniting Explosive Gases and Vapors

One of the greatest industrial hazards, particularly in munitions plants, is the ignition of explosive mixtures by static electric sparks. Vapors of solvents and gasolines and explosive dusts such as those of metal powders, flour, and coal are some materials that form explosive mixtures with air that may be ignited by static sparks. The question of the minimum energy necessary for such ignition is of fundamental importance in safety programs designed to avoid explosions, as well as in establishing the detailed mechanism of explosion phenomena.

The Physics Laboratory at the Pittsburgh Station has developed apparatus for precision measurements of minimum energies for gases and vapors and has measured mixtures of natural gas, ether, alcohol, and acetone vapors with air. Figure 19 shows the stainless steel explosion bomb and some of its accessory apparatus, including valves for admission of the gases and electric condensers for regulating the capacity of the system. The bomb is fitted with two electrodes terminating in small spheres. The distance between the spheres is accurately set by means of micrometer screws. After admission of measured amounts of dry air and combustible vapor, single electric sparks are passed across the gap between the spheres The energy in these sparks is regulated by precise control of the voltage on the delivery side of the high-voltage generating system shown in figure 20 and by a system of accurately calibrated condensers. The room containing the apparatus is equipped with air humidity-control apparatus, so that a constant relative humidity of 15 to 20 percent is maintained. This investigation is being continued to determine the conditions responsible for electric sparks which create dust explosions, and to develop the means for obviating this hazard.

New equipment was devised for some of the studies of the inflammability and explosibility of powdered metals and synthetic resins and their raw materials (see fig. 21). A metal-clad explosion chamber is mounted vertically, with a Bureau of Mines manometer connected to the top and auxiliary equipment mounted around it. The first group of powders of greatest hazard includes magnesium, aluminum, binary alloys of these two, titanium, and zirconium. The second group comprises metal powders of medium hazard and contains reduced and carbonyl iron, antimony, manganese, zinc, silicon, and tin. The third group, of least hazard,

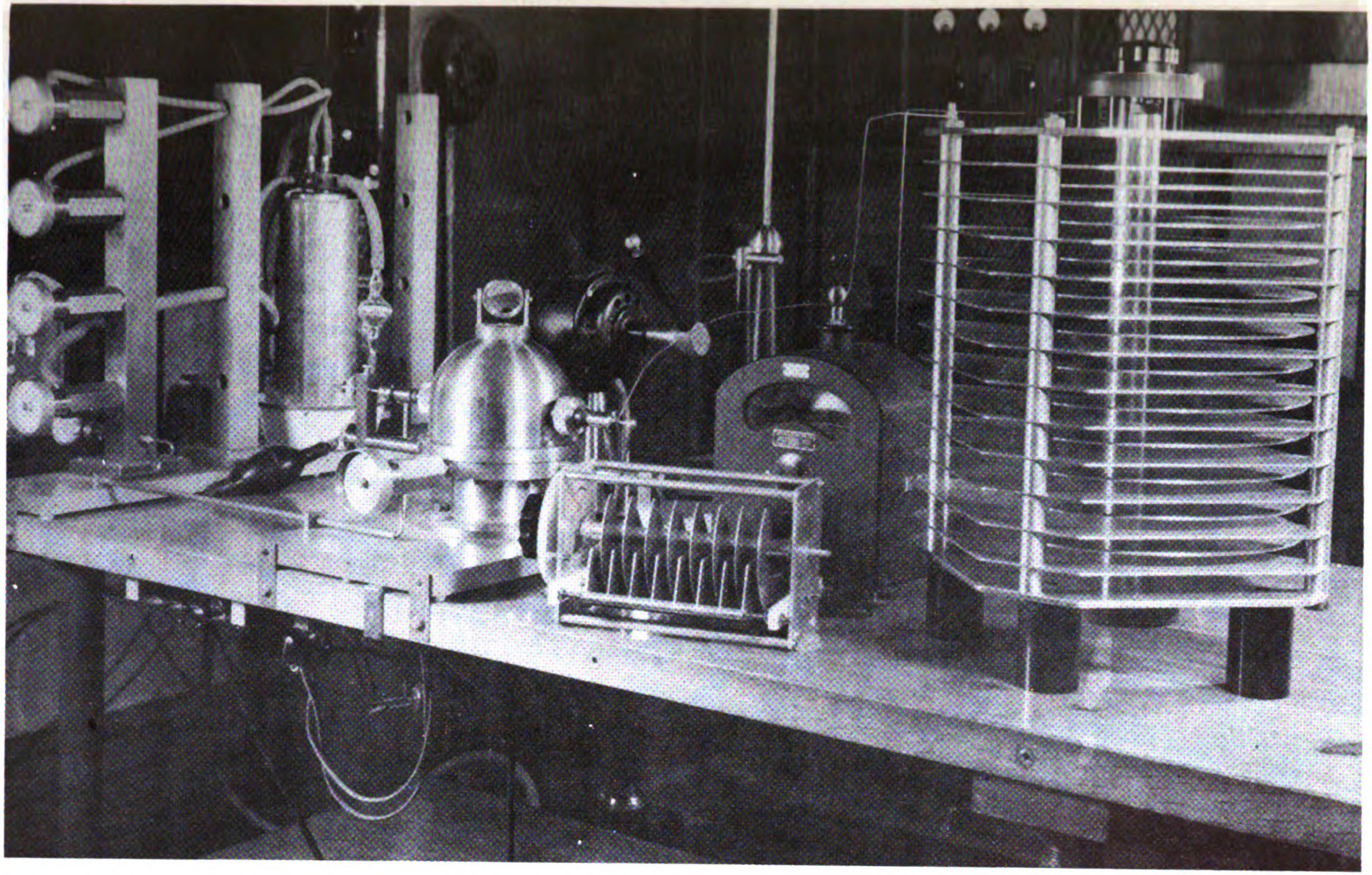

Figure 19.- Explosion bomb, control valves, voltmeter, condensers.

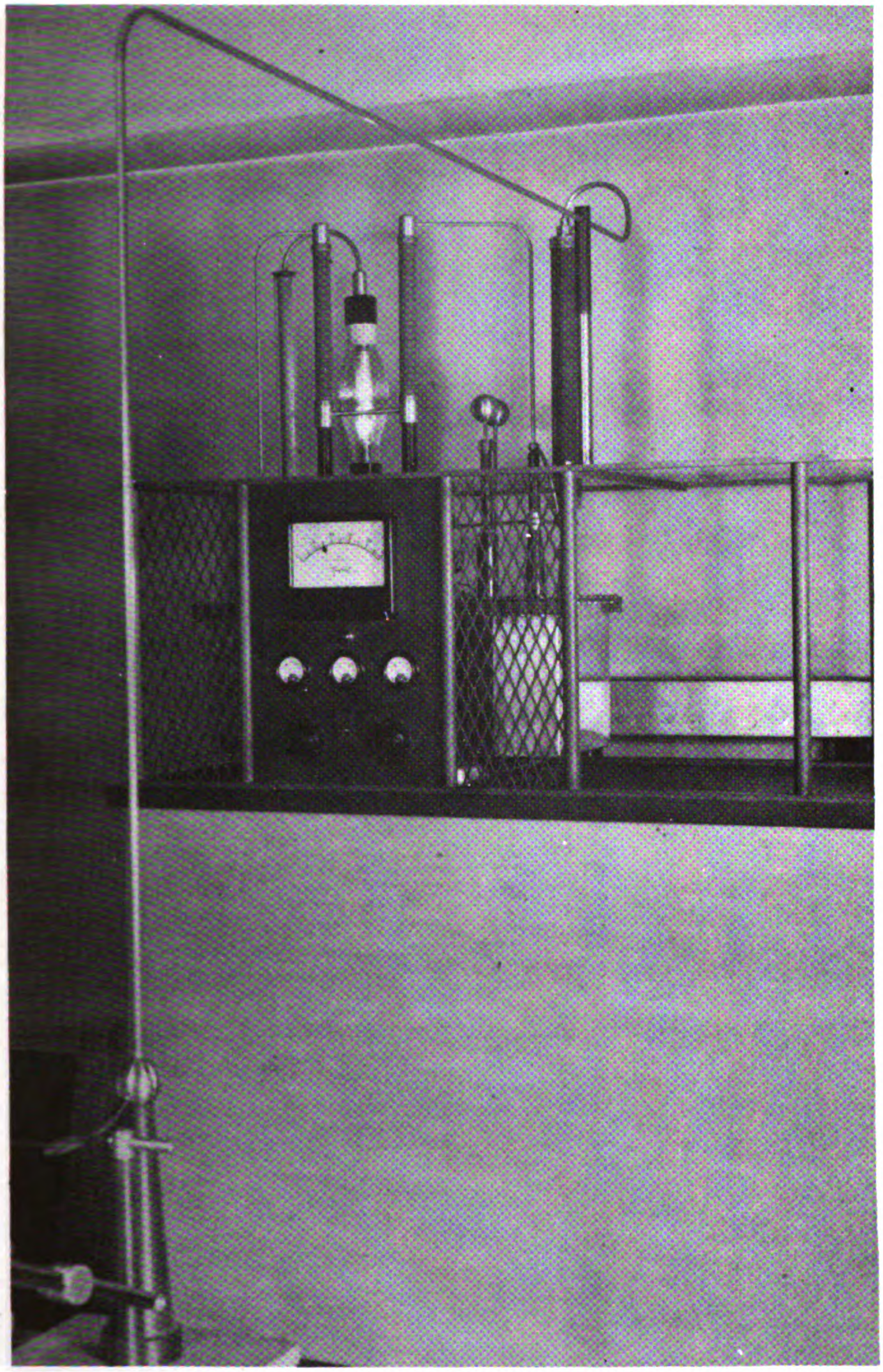

Figure 20.- High-voltage generator.

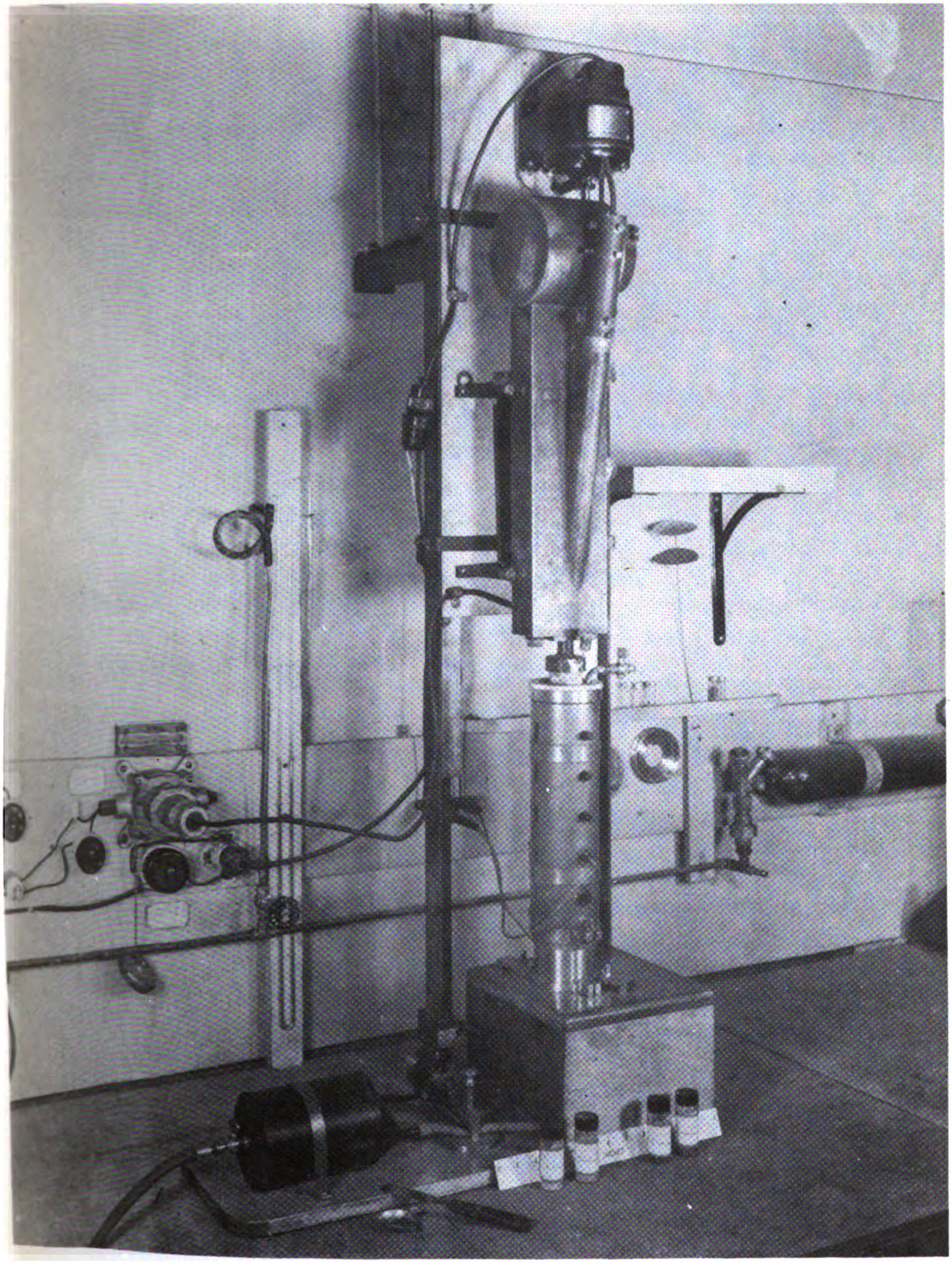

Figure 21.- Hartmann explosion test apparatus.

contains cadmium, copper, chromium, and lead. Appropriate portions of these data were used by the committee that formulated a Code for Explosion and Fire Protection in Plants Producing or Handling Magnesium Powder or Dust, adopted by the National Fire Protection Association in May 1943.

Extinguishing Magnesium Fires

Loss of life, injury to employees, and destruction of property by explosions and magnesium fires have directed attention to the necessity of developing a satisfactory method of extinguishing such fires.[35] Any loss in production facilities due to fire or explosion is a blow to our war efforts, and the seriousness of the problem is apparent when it is realized that neither water nor any of the other generally accepted types of fire extinguishers will extinguish a magnesium fire, but, rather, will greatly intensify its burning. Magnesium burns at 2,500° F. The present study has shown that hard pitch derived from coal tar in granulated or flaked form is effective for extinguishing most magnesium fires. When carefully spread over the surface of a fire the pitch softens and seals it from the air. In addition to its effectiveness, it is nonabrasive and available at low cost. From all indications, it can also be used for extinguishing small aluminum, zinc, and other metal fires.

Preventing Spontaneous Mine Fires in Subbituminous Coal

The possibility of reducing the danger of spontaneous combustion in the Suntrana mine in the Healy River Field of Alaska was studied. This is a subbituminous coal, and the loss of moisture to the mine air current causes shrinkage of the solid coal along passageways. Deep cracks open in the mass, and contact of air with the freshly exposed surfaces promotes heating. Experiments indicated that coating the ribs of the passageways with a suitable asphaltic-tar paint as rapidly as mining creates the new rib surfaces probably would retard the loss of moisture sufficiently so that disintegration of the faces would be eliminated and thus prevent rapid self-heating of the surface.

PREPARATION OF COAL

Very Low-Ash Coals for Production of Electrode Carbon

For reduction of aluminum from its ores, electrodes made from coke virtually free from ash are required. In normal times this requirement was filled by petroleum and pitch cokes, but with the present expansion of the aluminum industry these sources are inadequate. The Bureau of Mines has therefore searched for low-ash coking coals and has investigated methods for further reducing their ash contents for the purpose of supplementing the supply of electrode coke. The low-ash coals shown in table 1 were selected for test; float-and-sink and Trent process tests were applied. The results show that the Trent process was not nearly as efficient as the float-and-sink method for reducing the ash content of these coals.

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[35] Brown, H. R., Hartmann, I., and Nagy, J., Extinguishing Magnesium Fires with Hard Pitch Derived from Coal Tar: Bureau of Mines Rept. of Investigations 3672, 1942, 17 pp.

Removal of Phosphorus from Washington Coal

The recent expansion of electrometallurgical and chemical plants in the Pacific Northwest gave rise to greater demand for coke containing a low percentage of phosphorus. Shipping desirable coke into the area from the East involves high freight charge and, just at present, consumes precio rail and ship-bottom space needed for materials of war. It was desirable, therefore, to produce coke from the coking coals of Washington to satisfy the requirements of these industries. Although coke has been made from Washington coals since 1884, little has been known about their phosphorus content or the extent to which phosphorus could be reduced by cleaning. An investigation was undertaken, therefore, to determine the manner in which phosphorus occurs in the coking coals of Washington and its amenability to removal by ordinary coal-washing methods.[36] The phosphorus content of two beds studied (the east No. 2 and the west No. 3 at Wilkeson, Pierce County) is reduced greatly by the washing procedure required to produce coal of satisfactory ash content. In the other five beds examined, phosphorus is associated with the clean coal rather than with the impurity hence it cannot be eliminated by ordinary coal-cleaning methods. The lowest phosphorus content determined in the coals studies was 0.043 percent; a still lower percentage might be found in beds of coking coal formerly worked but that cannot be sampled now.

36/ Geer, M. R., Davis, F. T., and Yancey, H. F., Occurrence of Phosphorus in Washington Coal and Its Removal: Am. Inst. Min. and Met. Tech. Pub. 1586, 1943, 8 pp.

TABLE 1. - Trent process tests on coals originally low in ash

Mine	Bed	Location	Description	Ash in head sample, percent	Ash after Trent, percent
Empire....	Black Creek...	Walker County, Ala....	With flotation material....	3.14	2.69
Do........	do........	do.............	No flotation	3.40	2.13
Do........	do........	do.............	Egg coal	1.73	1.35
Boldman 5E	Elkhorn	Pike County, Ky.	+5-inch lump coal	3.83	2.92
Do........	Elkhorn No. 2.	do.............	5- x 3-inch egg coal	4.99	3.70
Do........	do........	do.............	3-inch nut and slack	7.64	3.86
Esco......	Elkhorn No. 3.	do.............	+5-inch lump coal	4.09	3.40
Bell......	Straight Creek	Bell County, Ky.	5-inch lump	.77	.65
Big Jim...	do........	do.............	6- x 3-inch egg coal	1.95	1.36
Esco......	Elkhorn No. 3.	Esco, Pike County, Ky.	5- x 3-inch egg coal	3.57	3.05
Do........	do........	do.............	3-inch nut and slack coal..	4.86	2.78
Big Jim	Straight Creek	Bell County, Ky.	+6-inch lump	1.76	1.61
Do........	do........	do.............	3- x 1/4-inch (crushed) ...	5.09	1.68
Bell	do........	do.............	+3-inch lump coal..........	1.39	1.28
Do........	do........	do.............	3- x 2-inch egg coal.......	1.55	1.49
Do........	do........	do.............	7/8- x 1/4-inch stoker coal	4.62	2.00
Blue Gem	Blue Gem	Whitely County, Ky. ..	....	1.28	1.17
Do........	do........	do.............	5- x 2-inch egg coal	1.48	1.34
Do........	do........	do.............	2-inch nut slack	4.91	3.53

Control of Sulfur and Ash in Mine-Run Metallurgical Coal

Uniformity of the sulfur and ash content of coke used in the iron blast furnaces is important for efficient operation of the furnace and, hence, is a factor in increasing the production of pig iron. Control of the amount of these impurities in the coal is necessary to obtain coke with both low and uniform sulfur and ash content. In some mines producing metallurgical coal, analysis of the coal bed shows wide variation in impurity content. To produce coal with low impurity analysis and minimum deviation, some mines practice grading, blending, selective mining, and surface preparation with satisfactory results. These methods were studied with the objective that similar practices might be introduced at other mines and made possible the use of metallurgical coal that otherwise could not be used for making coke because of high ash or sulfur or because of wide fluctuations in the content of these impurities.

Alaskan Coal

The shortage of coal in Alaska for military, railroad, and civilian use is a serious problem, involving, as it does transportation of coal by rail to Seattle and shipment to Alaskan ports by steamship or motorship.

To increase recovery of marketable coal at one of the three principal mines in Alaska (the Evan Jones mine at Jonesville) and to determine whether coal could be recovered from refuse dumps at this property, intensive washability studies were made, as a result of which specific recommendations for increasing the efficiency of the washing operations were made. Sampling and examination of the refuse dumps already accumulated revealed that approximately 50,000 tons of coal suitable for use in the power plant at Fort Richardson, which is being supplied by the Evan Jones mine, could be recovered in a simple auxiliary coal-washing plant with very little more labor than is required to mine the same amount of coal underground. The washability of the raw coal now being treated at the Evan Jones mine is illustrated by the data in table 2, which show the results of float-and-sink tests of the 3-inch slack.

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TABLE 2. - Specific-gravity analyses of 3-inch raw slack

Size	Specific gravity	Weight, percent	Ash,[1] percent	Cumulative	
				Weight percent	Ash,[1] percent
3-inch round-hole to 20 mesh. Weight, 91.4 percent.	Under 1.35	33.8	5.8	33.8	5.8
	1.35 to 1.50	26.6	21.1	60.4	12.5
	1.50 to 1.70	17.7	38.6	78.1	18.4
	Over 1.70	21.9	62.6	100.0	28.1
Under 20 mesh. Weight, 8.6 percent. Ash, 21.8 percent.[1]	Under 1.35	53.7	4.2	53.7	4.2
	1.35 to 1.50	16.9	19.3	70.6	7.8
	1.50 to 1.70	9.7	35.7	80.3	11.2
	Over 1.70	19.7	62.7	100.0	21.3
Composite, 3-inch round-hole to 0. Ash, 28.0 percent.[1]	Under 1.35	35.5	5.6	35.5	5.6
	1.35 to 1.50	25.8	21.0	61.3	12.1
	1.50 to 1.70	17.0	38.5	78.3	17.8
	Over 1.70	21.7	62.6	100.0	27.5

[1] Moisture-free basis.

Briquetting Subbituminous Coal

The briquetting process is a practical method of converting much of what is considered undesirable fuel into a usable form of domestic fuel.[37] Laboratory investigations on the briquetting of subbituminous coal and the determination of whether briquetting properties can be improved by drying with steam under pressure by the Fleissner process just before briquetting are discussed. A study of the properties of raw subbituminous coal containing 25 percent moisture, steam-dried coal containing about 6 percent moisture, and air-dried coal containing about 10 percent moisture is included. The protective effects of paraffin coating were studied, and the briquetting properties of Pocahontas coal were compared with those of subbituminous coal. It was found that briquets equal in quality to commercial briquets made from higher-rank coals could not be made from raw or steam-dried subbituminous coal. The characteristic tendency of subbituminous coals to slack and to disintegrate in the fuel bed showed itself to some extent in the properties of asphalt-bonded briquets. The heating value of briquets made from the steam-dried coal was about 12,200 B.t.u. per pound, compared with 10,900 B.t.u. per pound for briquets made from raw coal. The former briquets withstood normal weathering better, but

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[37] Parry, V. F., and Goodman, J. B., Briquetting Subbituminous Coal: Bureau of Mines Rept. of Investigations 3707, 1943, 37 pp.

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raw-coal briquets made a better showing during accelerated weathering. All subbituminous-coal briquets disintegrated somewhat during burning because this fuel had no coking properties. Addition of binder did not overcome this undesirable condition. Paraffin coating did not protect subbituminous-coal briquets.

The following tentative standards describe the physical properties of satisfactory commercial pillow-shaped briquets estimated from tests on briquets from eight plants: (1) Compressive strength made through parallel surfaces on pillow-shaped briquets should be at least 650 to 700 pounds per square inch; (2) the apparent specific gravity, measured by weighing a paraffin-coated briquet in water, should be about 1.20; and (3) the abrasion resistance should be not less than 70 percent as measured by the percentage of material passing a 0.263-inch square-hole screen after 5 briquets have been tumbled for 1,200 revolutions in the American Society for Testing Materials apparatus for the tumbler test for coal.

STORAGE OF COAL

Studies by the Bureau of Mines show that the loss of heating value of coal in storage commonly has been overestimated.[38] Tests show that the loss is negligible. The extent of slacking of coal in storage depends principally on the rank of coal. The lower-rank coals, such as lignite, subbituminous coals, and high-volatile, high-inherent-moisture bituminous coals slack from weathering much more readily than the higher-rank coals. Changes in burning characteristics may occur in some coals in storage. Such changes are primarily important for slack-size coals. For example, the caking tendencies of the coal may decrease appreciably. Storage might improve the coal for use on domestic underfeed stokers or chain-grate stokers; for spreader stokers it would make little difference; for large underfeed stokers efficiency might be affected. There also may be slight changes in the mineral matter of the coal, which oxidizes to some extent. Whether or not under certain storage conditions a given coal will heat from spontaneous combustion to any undesirable extent depends on many complex factors. Satisfactory storage of anthracite does not present much of a problem.

To assure absolutely that undesirable heating will not develop in any stored bituminous or subbituminous coal,[39] it is necessary to employ

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[38] Barkley, J. F., The Storage of Coal: Bureau of Mines Inf. Circ. 7235, 1943, 14 pp.

[39] Barkley, J. F., Safe Storage of Bituminous Coal: The Chicago Purchaser, Feb. 1942. Also in The Philadelphia Purchaser, Feb. 1942.

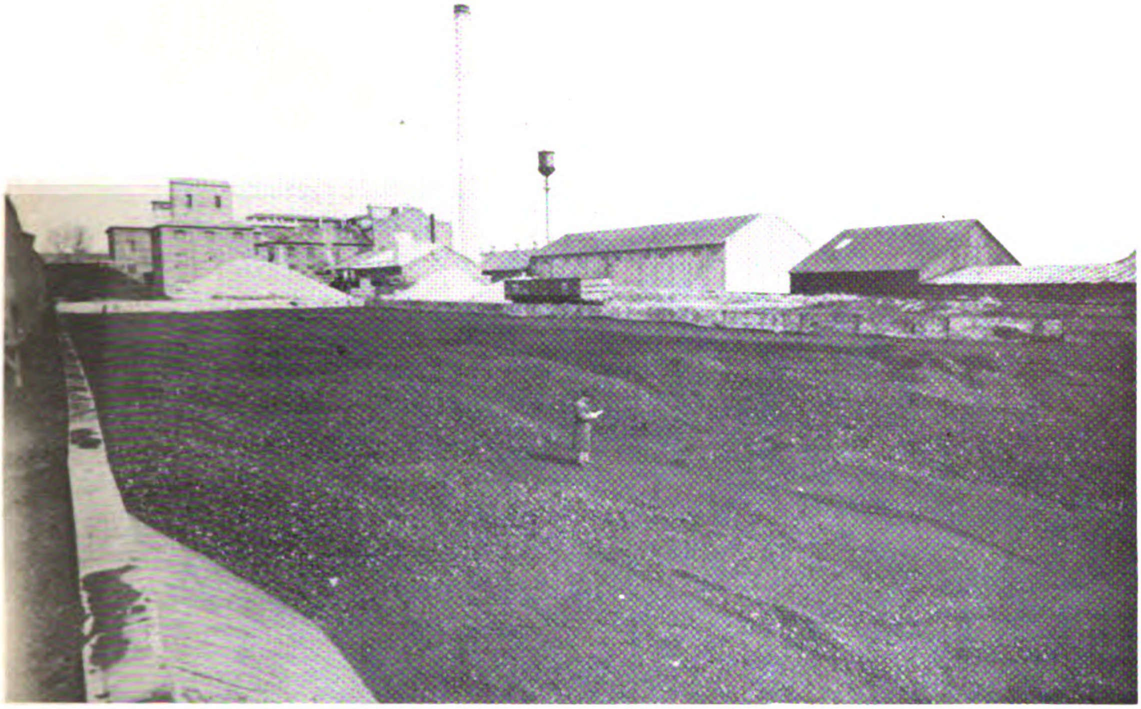

Figure 22.- Storing of subbituminous slack coal in 4-foot benches in open pit, Great Western Sugar Co., Brush, Colo.

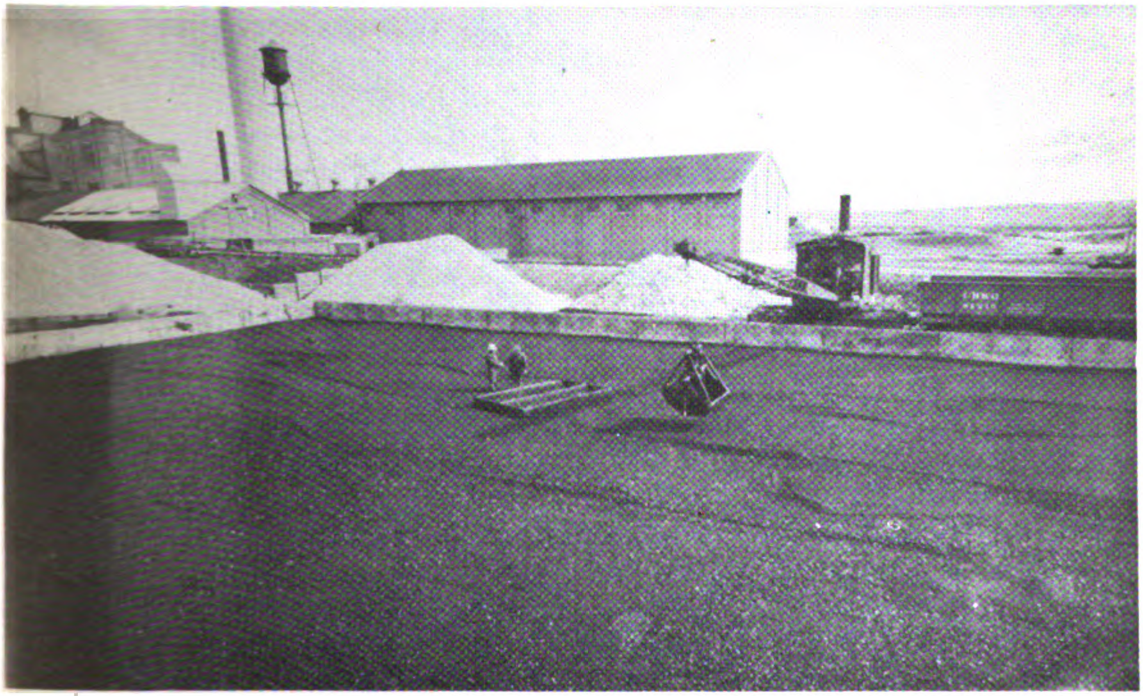

Figure 23.- Top of second bench and method of leveling.

methods of storing that either entirely prevent access of air to the coal or provide for access of enough air throughout the pile to carry away the heat as rapidly as it develops. Methods that should be considered include storing coal under water; storing slack coal in layers 2 to 3 feet thick on hard or compacted earth or clay; storing slack coal in small, low piles, say 6 feet, without compacting; storing slack coal in bunkers or silos without segregating sizes; and storing sized coals with the fines completely removed. Any rapid rise in temperature is noted periodically.

Methods of storing large quantities of subbituminous slack coal in open pits were studied further. A 200-ton lot of this coal was stored thus successfully for 8 months. The coal was placed in 3-foot benches to a depth of 6 feet in a dry concrete pit formerly used for storing this fuel under water. None was piled higher than 4 feet. The bench was not compacted after it was leveled, and it assumed its normal density of about 50 pounds per cubic foot. Thermocouple wells were placed in different parts of the pile to obtain information on changes in temperature during storage. Physical and chemical changes were determined. Results indicated that fresh and stored coal were not significantly different. The top had slacked for about 2 inches to form an effective seal for the pile. Table 3 gives analytical data on the properties of the coal before and after storage and analytical results on samples extracted at different levels in the pit. This test demonstration showed certain points regarding storage of this particular subbituminous slack coal: (1) If air circulation is minimized by sealing the sides of a lot of coal placed 6 feet deep in 3-foot benches and distributed to eliminate segregation, spontaneous combustion does not occur; (2) air enters the coal from the top by diffusion, and the rate of oxidation depends on the resistance to movement of air by convection from the top; (3) the amount of oxygen absorbed by this subbituminous slack coal stored under favorable conditions for 8 months in an open pit is approximately 0.4 percent by weight of the coal. The net reduction in heating value is about 0.8 percent as a result of oxidation. This indicates that part of the oxygen reacting with the coal passed off as CO_2 or other products of oxidation; (4) no significant changes in physical or chemical properties occurred; and (5) temperature gains at the rate of about 2° F. per day for 20 to 30 days were registered. Thereafter, the coal was less reactive, and the temperature remained constant or receded or advanced slightly; (6) weathering occurred in the top 2 inches but was insignificant below this top layer, and (7) engineers who used the stored coal on a chain-grate stoker reported better performance with this fuel than with road coal direct from the mine mixed with coal that had been stored under water, probably because of better distribution of moisture. Storage of this coal at Brush, Colo., is shown in figures 22 and 23.

TABLE 3. - Changes in physical and chemical properties of subbituminous slack in open-pit storage[1]

Location	Entire Before[2]	Entire After[3]	0-2 in.	0-2 in.	0-18 in.	0-18 in.	20-38 in.	20-38 in.
Date sampled	3/30/42	11/16-17/42	5/25/42	8/4/42	5/25/42	8/4/42	5/25/42	8/4/42
Chemical analysis:								
As received:								
H_2O	21.1	24.3	8.6	12.3	22.7	23.1	22.4	24.4
Volatile	30.5	29.4	35.4	34.1	29.5	30.1	29.6	30.3
Fixed carbon	43.2	41.2	49.9	47.9	42.4	41.1	42.6	40.4
Ash	5.2	5.1	6.1	5.7	5.4	5.7	5.4	4.9
B.t.u.	9,830	9,310	11,190	10,350	9,520	9,410	9,580	9,410
Moisture-and ash-free:								
Volatile	41.4	41.7	41.6	41.7	41.0	42.4	41.0	42.8
Fixed carbon	58.6	58.3	58.4	58.3	59.0	57.6	59.0	57.2
Hydrogen	5.2	5.1	-	-	-	-	-	-
Carbon	76.9	76.6	-	-	-	-	-	-
Nitrogen	1.7	1.7	-	-	-	-	-	-
Oxygen	15.7	16.1	-	-	-	-	-	-
Sulfur	.5	.5	-	-	-	-	-	-
B.t.u.	13,350	13,190	13,130	12,640	13,250	13,230	13,280	13,300
Slacking index	65.0	61.9	-	-	-	69.8	69.7	63.1
Friability, percent	23.6	30.2	-	-	-	30.8	29.6	27.3
Screen analysis, square hole:								
Cumulative percent return on -								
2-inch	3.5	4.6	-	-	-	-	-	-
1-1/2-	12.5	11.4	-	-	-	-	-	-
1-	26.0	27.3	-	-	-	-	-	-
3/4-	38.7	35.7	-	-	-	-	-	-
1/2-	49.8	51.9	-	-	-	-	-	-
1/4-	70.7	69.2	-	-	-	-	-	-
1/8-	84.4	84.2	-	-	-	-	-	-
Pan	100.0	100.0	-	-	-	-	-	-
Average size, inches	.694	.688	-	-	-	-	-	-
Weight per cubic foot, lbs.	48.5	46.0	-	-	-	-	-	-

[1] 200 tons of coal 6 feet deep in two 3-foot benches in concrete pit.

[2] Sampled as coal was placed in pit, 175 6-pound increments.

[3] Sampled as coal was extracted from pit, 175 6-pound increments.

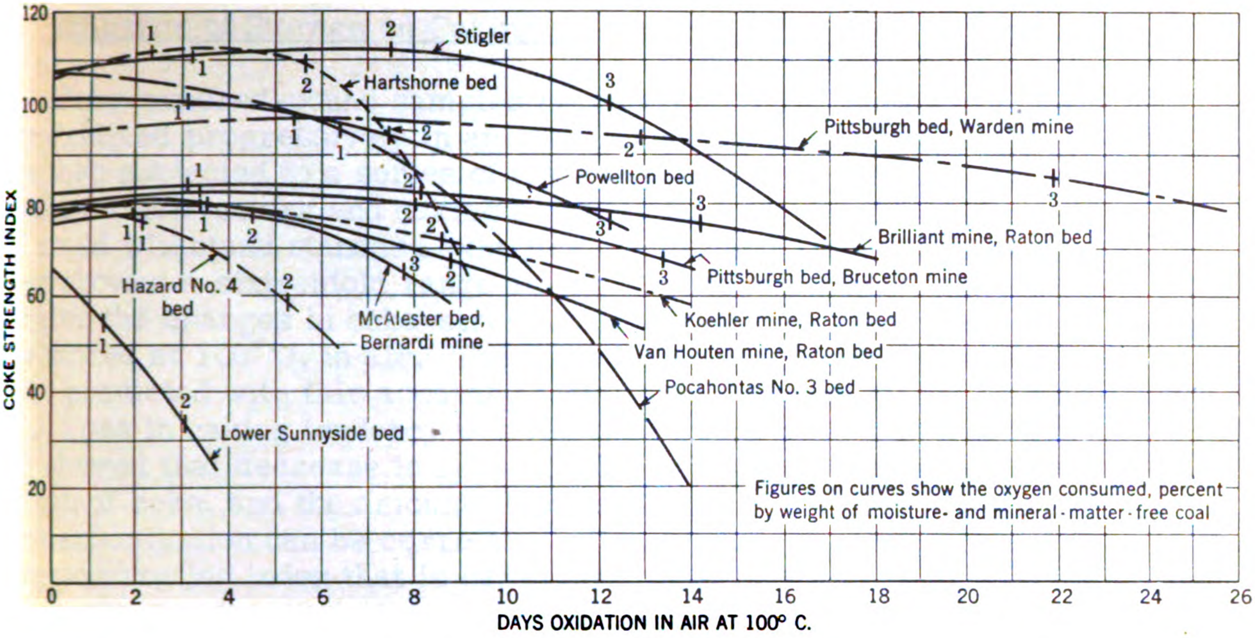

Figure 24.- Effects of storage (accelerated) of coal on strength index of coke.

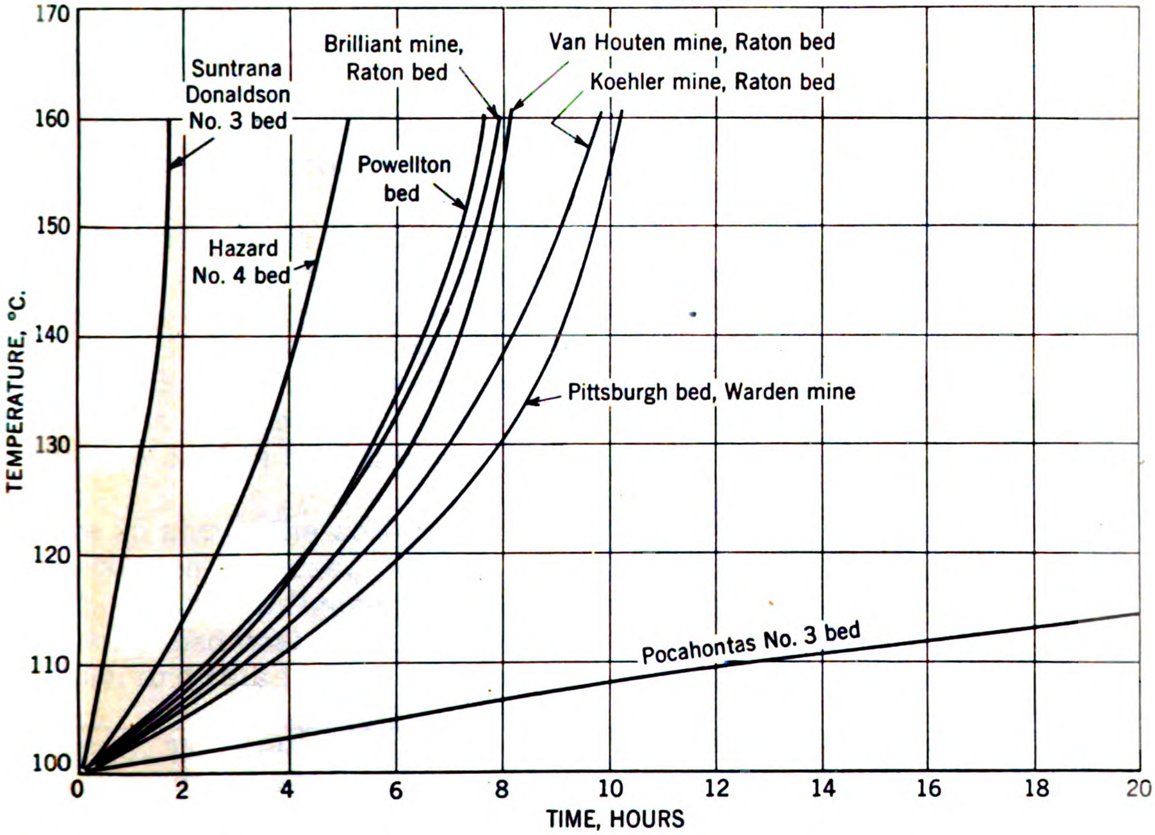

Figure 25.- Self-heating of coal from 100° C. in an atmosphere of 85 percent oxygen.

Influence of Storage on Caking and Coking Properties of Coal

Four-hundred-pound samples representative of 15 different coal beds were oxidized progressively in an accelerated weathering apparatus and were then subjected to a series of tests to follow the changes in various aspects of their coking and caking behavior.40/ The length of time each coal could withstand standard oxidizing conditions before losing its coking power showed a sixteenfold range among the coals tested. Figure 24 illustrates the changes in coke-strength index that took place when these coals were stored at 100° C. in air. The durability of coking power of most coals can be predicted with fair accuracy from their analyses by the method developed. Loss in caking tendency was followed by several different tests. Results showed that decrease in agglutinating values predicts decreased strength of coke, and the amount of unfused char remaining in the retort after carbonization can be correlated with strength of coke and also with the agglomerating index that is based upon classification of coke buttons made in the standard volatile-matter test. The caking tendency of coals can be reduced greatly by storage or oxidation long before the true loss in heating value exceeds 1 or 2 percent.

Spontaneous Heating of Stored Coal

Any procedure whereby the relative tendency of coals to heat spontaneously in storage can be predicted or determined in the laboratory is of importance to commercial users of coal who must store it in large amounts. A tentative laboratory method has been developed for this purpose.

A sample of coal is dried in an inert atmosphere and placed in a steam-jacketed, cylindrical, iron container. The temperature of the coal sample is raised to 100° C., and a stream of oxygen is passed up through the coal column. Thermocouples are placed at suitable positions in the coal column, and as the temperatures of coal rise above 100° C., the rate of flow of oxygen is increased so that constant oxygen concentration in contact with the coal is maintained.

Figure 25 shows the self-heating curves obtained by testing eight coals from various sources. Table 4 gives the rank and the source of the coals tested. From the figure it is clear that the sample of Suntrana mine, Donaldson No. 3-bed coal shows very much greater tendency to heat spontaneously, and this is borne out by the troubles with mine fires that

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40/ Schmidt, L. D., Elder, J. L., and Davis, J. D., Influence of Storage on Caking and Coking Properties of Coal: Ind. and Eng. Chem., vol. 35, No. 2, Feb. 1943, pp. 150-155.

have been experienced in producing this coal. The Pocahontas No. 3-bed sample shows little tendency to heat as compared with the other coals tested. Each of these coal samples gave a characteristic self-heating curve, and as they were all tested under the same conditions as regards particle size, initial temperature, and oxygen concentration, these curves are characteristic of the individual coal substances. The test method gives reproducible results for the curve for Warden-mine coal is the average of several determinations, none of which differed from the average by more than 2 percent.

TABLE 4. - The source and rank of the coals used in the spontaneous-heating tests

Bed	Source	Rank
Pocahontas No. 3..	McDowell County, W. Va.	Low-volatile.
Pittsburgh	Warden mine, Allegheny County, Pa.	High-volatile
Raton	Koehler mine, Colfax County, N. Mex.	Do.
Do....................	Van Houten mine, Colfax County, N. Mex...	Do.
Do....................	Brilliant mine, Colfax County, N. Mex.	Do.
Powellton	Coal Mountain mine, Wyoming County, W. Va.	Do.
Hazard No. 4	Columbus No. 4 mine, Perry County, Ky. ..	Do.
Donaldson No. 3 ...	Suntrana mine, Suntrana, Alaska	Subbituminous

UTILIZATION OF COAL

Combustion

Fuel-Engineering Service

The Fuel-Engineering Service is a consulting service rendered to Federal agencies with respect to the selection and use of fuels and equipment for burning fuels. Surveys were made of the fuel-burning equipment for the new Naval Training Stations at Port Deposit, Md., Newport, R. I. and St. Albans, Long Island, which resulted in improved operations. The War Production Board requested an investigation of a new-type magazine stove for fireplaces. Operating costs were compared and equipment and fuels were converted for Howard University, veterans' facilities, Department of Agriculture, Department of Justice, District of Columbia Home for the Aged, Columbia Institute for the Deaf, War Department, Gallinger Hospital, and St. Elisabeth's Hospital. Acceptance tests on new equipment purchased by the Government were witnessed.

Boiler Feed-Water Conditioning

The total number of water analyses, 6,847, for this fiscal year is mo than double that of the previous year. Reports were made on analyses of two boiler compounds and 11 boiler scales, sludges, or deposits. Five hundred ninety-three special Bureau of Mines field boiler-water test kits, 2,620 bottles of chemical reagents, and 1,200 test-kit items were distributed to Army Posts in this country and overseas. An investigation was made for the War Department on compounds of amines for alkalinizing the steam condensate in return lines. At the time of the investigation the Army was using amines at a cost of about $50,000 per year. By devising a new type of indicator different from that supplied by the manufacturer, a saving of about $8,000 is expected in the use of this material.

The questions and answers handbook[41] was revised and brought up to date. This handbook gives information about boiler-feed water to boiler operators who have not studied chemistry. The boiler operator must apply some chemistry, whether or not he understands it. He usually receives, with equipment, instructions as to "how" to proceed; but if he does not know "why", he cannot achieve full effectiveness. This handbook will help the operator to understand the essentials of boiler feed-water conditioning.

Tannin and similar complex organic materials are being used increasingly in boiler feed-water treatment.[42] For example, the phlobatannin quebracho will frequently reduce dissolved oxygen concentration, prevent hard scale, retard clogging of feed lines and injectors, and inhibit caustic embrittlement. Analytical procedures were developed for determining dissolved tannin. It has been found that the concentrations measured by these tests can be correlated in some degree with quantities of tannin fed and with experimental determination of their effect in the boiler water.

For over 30 years, investigation and discussion of embrittlement have revolved around research from a few laboratories in the United States and in one or two foreign countries. A summary[43] of the papers composing the symposium on caustic embrittlement under the auspices of the Joint Research Committee on Boiler Feed-Water Studies of the American Society of Mechanical Engineers shows (a) how to determine that a boiler water is embrittling and (b) methods that may be followed to make it nonembrittling. Effective chemical inhibition of embrittlement presumably results from the reaction of the treating chemical with the steel surface to produce a protective film. The results obtained by the contributors are grouped to show that certain tannins, especially those of the quebracho type, will retard embrittlement cracking in test specimens. Relatively low concentrations are sufficient, even at high pressures. The protective action probably decreases around 500 psi, although the tannin has been used successfully in several cases at 650 psi. Lignins will prevent cracking of test specimens in many boiler waters. One investigation has indicated that their protective action may be increased by the use of a small amount of sodium nitrate. Sodium sulfate did not prevent embrittlement cracking in the test specimens. The combination of sodium sulfate and sodium chloride does not prevent cracking in embrittlement-detector tests at pressures higher than 250 psi. Boiler water containing sodium hydroxide in appreciable concentration cannot be treated with sodium phosphate to prevent cracking in specimens. Embrittlement can be prevented by eliminating from the boiler water all alkalies that will yield sodium hydroxide when the water is concentrated. The pH in the boiler water is then maintained by the use of sodium phosphate. Sodium nitrate appears to inhibit embrittlement in the detector tests, at least up to 300 psi.

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[41] Barkley, J. F., Questions and Answers on Boiler Feed-Water Conditioning: Bureau of Mines Handbook 3, 1943, 121 pp.

[42] Berk, A. A., and Schroeder, W. C., Determination of Tannin Substances in Boiler Waters: Ind. and Eng. Chem., vol. 14, No. 6, 1942, pp. 456-459.

[43] Schroeder, W. C., and Berk, A. A., Summary of Papers Composing the Symposium on Embrittlement: Trans., Am. Soc. Mech. Eng., vol. 64, No. 5, July 1942, pp. 427-430.

Smoke Abatement and Air Pollution

Work was continued on the formulation of a model smoke law by a committee of the American Society of Mechanical Engineers. In the present war emergency, industrial production of the Nation is being accelerated. Smoke-regulation departments of municipal and State governments can help materially in solving problems of efficient burning, coal storage in homes and at plants, and coal allotment.[44]

Each winter as furnaces are lighted for heating and cooking, carbon monoxide has taken its toll of deaths and serious accidents.[45] Coal, coke, wood, oil, gasoline, kerosene, natural gas, and manufactured gas may produce carbon monoxide on burning. Many unsafe heating appliances are being used. Methods of preventing such accidents are presented in a paper on the danger from carbon monoxide in the home.

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[44] Barkley, J. F., How Smoke-Regulation Departments Can Assist in the War Project of the Control, Allotment, and Conservation of the Nation Coal: Smoke, vol. 9, No. 8 July 1942. Also in Solid Fuel Eng., vol. 1, No. 11, Aug. 1942, pp. 6-7.

[45] Berger, L. B., and Schrenk, H. H., Danger from Carbon Monoxide in the Home: Bureau of Mines Inf. Circ. 7238, 1943, 8 pp.

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How to Save Fuel

It will be very helpful to the whole war program to have every householder and plant operator use fuel without waste.[46] This offers a practical and effective way for everyone to contribute to the national welfare. The problem of saving fuel is one of saving heat. It has been estimated that 55,000 coal miners working one year would be needed to mine the coal that can be saved by proper preparation and efficient use of equipment, that is, by improving combustion, blowing down boilers as little as possible, stopping leaks, and insulating all possible hot surfaces.

Home Insulation

One of the chief elements in fuel saving is insulation.[47] To the ordinary home owner, insulation is simply a more or less effective barrier to retain heat in winter and exclude it in summer. Common insulating materials are mineral wool (also called rock wool, glass wool, and slag wool), vegetable and wood fiber in various forms, asbestos, insulating boards made of vegetable or mineral products, vermiculite, diatomite, pumice and other porous rocks or earths, magnesia, aluminum foil, sawdust, animal hair, and cork. Aside from the conservation of fuel, insulation also assists in maintaining comfortable temperatures without subjecting the occupants of rooms to chills and drafts, thus protecting public health; protection against fire is another function of insulation; homes well insulated require redecorating less frequently, because side walls and ceilings are kept drier.

Stability of Burner Flames

On ignition of an explosive gas mixture, combustion takes place within a narrow zone, separating burned and unburned gas, which propagates as a Huyghen's wave, in a direction normal to itself, into the unburned gas at the rate at which combustion reactions are induced in successive gas layers by the process of heat transfer (essentially conduction) and diffusion of active species. The rate of progress of the combustion zone is called the burning velocity. It has been shown[48] that a burner flame remains stationary above the orifice because there are regions, either near the rim or nea an obstruction in the stream, such as a grid over the top of the burner, whe the gas velocity equals the burning velocity. This balance is destroyed whe the gas velocity at the boundary of the obstruction is reduced below a critical limit when the flame flashes back; when it is raised above a higher critical limit, the flame blows off. These two limits are independent of burner diameter, except for extreme sizes. Their values can be determined from hydrodynamic equations and data on gas velocities at the flashback and blow off limits. This was done for mixtures of natural gas and air and for ordinary upright and inverted flame cones. The latter are formed when an obstruction such as a wire is mounted in the center of the gas stream. (See fig. 27.) The gas-flow pattern was studied experimentally by photographing stroboscopically illuminated magnesium oxide-dust particles. (See figs. 26 and 27.) No appreciable redistribution of velocities over the cross section of the stream was observed below the combustion zone. The burning veloci was found constant over the surface of the inner cone except at the tip, whe it increases to the axial gas velocity, and at the base, where it decreases to zero. The experimental flame-cone outline and flow pattern agree with the theoretical within the limitations imposed by simplifying assumptions. The temperature distribution of the flame was determined by the sodium line-reversal method, only the center of the flame being colored. (See fig. 28.)

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[46] Barkley, J. F., How to Save Fuel at Home: Bureau of Mines Inf. Circ. 7229, 1942, 5 pp. Also in Coal-Heat, vol. 43, No. 2, Feb. 1943, pp. 36-37.

Barkley, J. F., Prevent Fuel Waste for War: Power Plant Eng., vol. 47, No. 4, April 1943, p. 75. Also in Ind. and Power, vol. 44, No. 4, April 1943, pp. 140-141; Supervision, vol. 5, No. 4, April 1943, p. 18 Coal-Heat, vol. 43 No. 4, April 1943, p. 10; Combustion, vol. 14, No. 10, April 1943, p. 47; Coal Herald, vol. 17, No. 1, April 1943, p. 19; Heat. and Vent. vol. 40, No. 5, May 1943, p. 40; and Sou. Power and Ind., vol. 61, No. 5, May 1943, p. 100.

[47] Bowles, Oliver, Home Insulation with Mineral Products. Conservation of Fuel for War: Bureau of Mines Inf. Circ. 7220, 1942, 11 pp.

Properties of Coal Ash as Related to Clinkering and Slagging

The study of the flow properties of coal-ash slags at high temperatur has been continued, with particular emphasis on the behavior of slags in th range of plastic viscosity, that is, where crystals of solid material are pre sent in the otherwise fluid material. These crystals interact to produce the effect of an internal structure, and an internal yield stress is said to exist for the slag. A definite amount of stress must be applied to such a slag before shear will occur at a measurable rate, as opposed to purely liquid slags where the application of any stress results in a strictly propor tional rate of shear. This factor is extremely important in fixing the thick ness of slag on the heat-absorbing surfaces of large central-station boiler because the development of an internal structure in a slag reliably prevent the flow of that slag under nominal loading, such as the action of gravity. Thus, slag deposited on furnace wall tubes will tend to become excessively

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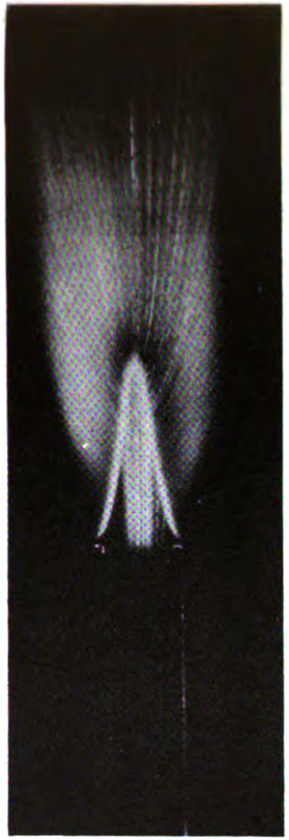
[48] Lewis, B., and von Elbe, G., Stability and Structure of Burner Flames: Jour. Chem. Phys., vol. 11, 1943, pp. 75-97. Also in Carnegie Inst. o Tech., Coal Research Lab. Contribution 109, 1943, 55 pp.



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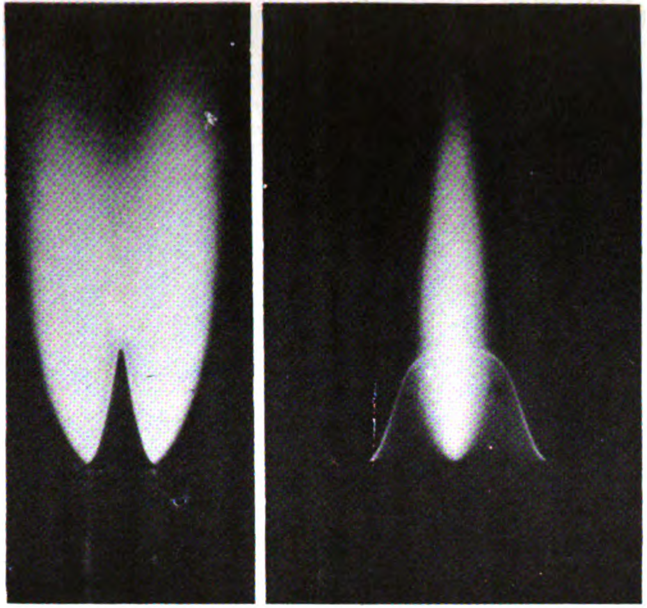

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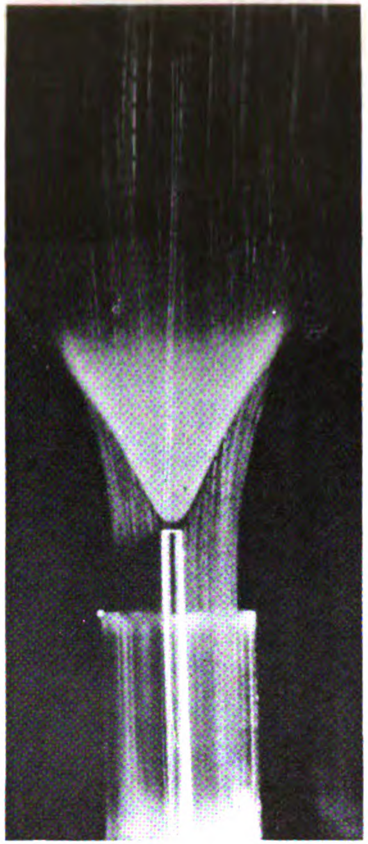

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Figure 26.- Tracks of stroboscopically illuminated magnesium oxide particles in a flame burning on a rectangular tube of 0.755 cm. X 2.19 cm. cross section. The short side of the burner tube faces the camera. The light beam, ca, 1 mm. wide and several cm. high, bisects the long side. Time between interruptions, 1.44 X 10^{-3} sec. Mixture composition, 7.50 percent natural gas in air; gas flow, 204 cc./sec.

Figure 27.- Inverted flame cone with particle tracks. Tube diameter, 1.717 cm.; wire diameter, 0.211 cm.; mixture composition, 6.20 percent natural gas in air; gas flow, 168 cc./sec. Particles invisible in shadow of wire on the left.

Figure 28.- Front and side views of flame on rectangular burner colored centrally with sodium chloride.

thick if the temperature at which the slag can develop a structure is high as compared to furnace temperatures; this excessively thick slag will serve to thermally insulate the wall tubes against the high temperatures in the furnace, and the output of the water wall tubes will therefore be reduced. If the tendency to develop an internal structure does not exist, the slag will flow under the influence of gravity, and the thickness of the resultant slag layer will be determined only by the liquid viscosity of the slag and the temperature gradient through the deposit. The methods of test developed in this investigation permit measurement of temperatures at which this structure is effective and quantitatively to determine its magnitude. Previous work on this phase of the investigation was concerned primarily with the development of satisfactory methods of test; experimental work this year consisted of routine determinations of these flow properties for a large number of synthetic slags having compositions representative of the most common coal ashes.

Burning Solid Fuels on Traveling Grates

This investigation is concerned with determining the fundamentals involved in the combustion of fuel on the crossfeed principle. Tests have been completed on four coals ranging in rank from high-volatile A bituminous to subbituminous B from Colorado. Fundamental differences in the behavior of various fuels have been observed, including an increase in the rate of ignition travel with decrease in rank for anthracites; whereas with decrease in rank below high-volatile A bituminous coal, the rate of ignition travel decreases. This factor is important in chain-grate stokers, because ignition must occur before combustion can take place. The study showed that (1) rate of ignition travel varies only with thin-burning-layer fuel beds; (2) predrying the coal in the lower portion of the bed before ignition may aid in accelerating ignition and burning rates in this zone; (3) higher temperature of the furnace apparently acts to increase the rate of ignition travel, and (4) reduction in size of the coal because of breakage on heating can cause a more rapid rate of ignition travel than would have occurred for the originally charged fuel.

Reactivity of Solid Fuels by the Ignition-Point Method

Reactivity of the fuels being tested in the crossfeed investigation has been measured in the ignition-point apparatus to permit correlation with observed burning characteristics. Reactivity tests also have been made on fuels ranging from charcoal to high-temperature coke, the same fuels being burned experimentally in an open grate, where it was found that a definite relationship existed between the reactivity and the time required for the fire to reach the maximum burning rate. This relationship was most exact for fuels of moderate reactivity. It was found that computing the reactivity as the logarithm of the self-heating rate of the fuel in oxygen at a temperature of 500° C. was most useful in using the data from the ignition-poin apparatus. If this value were decreased below a certain critical quantity, the fuel would no longer be self-burning; or, in case a coking coal was being burned, the resultant coke would extinguish unless it had a greater reactivity.

External Corrosion of Furnace-Wall Tubes

Many large central-station boilers have been forced out of operati for replacement of wall tubes because of thinning of the tubes by external corrosion. Investigation showed that the conditions causing corrosion were identified with the composition of the gases in contact with the tube wall, corrosion occurring in a definite pattern wherever the gases were reducing, that is, when they contained more than 1 percent carbon monoxide. Introduction of air through the spaces between tubes or readjustm of burners to maintain oxidizing conditions at the tube surfaces essentia prevents further attack. Laboratory work has been directed towards identifying the constituents present in corrosion products from actual tube surfaces, of reproducing these corrosion products by controlled tests in experimental furnaces, of studying some of the systems involve by means of X-ray diffraction and other methods, and of consideration o temperature gradient, rate of heat transfer, and thermal conductivity of normal deposits in affecting the rate at which corrosion can occur.

Preparation and Combustion of Mixtures of Coal and Oil

The shortage of fuel oil in parts of the United States has revived interest in the mixing of oil with coal to produce a fuel suitable for use in oil-burning industrial furnaces without material alteration in equipment.[49] In marine use, oil-coal mixtures have two fundamental advantages over oil alone: (1) Coal is more universally distributed, and shipping difficulties, for at least part of the fuel, may be decreased; an (2) the heat content per unit of volume is about 1 to 4 percent greater, which allows some saving in bunker space. During war, however, any increase in the ash content of a fuel used for marine purposes is undesirable, as it may increase the oil slick produced on the surface of th water. The higher the ash content, the longer the trail is visible and th more easily it may be followed by enemy vessels. The development of oil-coal mixtures for use in stationary oil-burning equipment was studi

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[49] Schroeder, W. C., Use of Mixtures of Oil and Coal: Mech. Eng., v 64, No. 11, 1942, pp. 793-804. Discussion and author's closure: Mech. Eng., vol. 65, No. 4, April 1943, pp. 278-284.

The most difficult problem in dealing with oil-coal mixtures has to do with keeping the coal in suspension. Where burning demonstrations with coal-oil fuel have been made, the results have apparently been quite successful. However, the tests usually have been conducted on small boilers for relatively short periods of time and there has been a distinct failure to observe or make public the details of the tests. More extensive tests must be made before there can be any widespread use of "colloidal" fuel.

Carbonization

Carbonizing Properties of American Coals

In the survey of the coking properties of American coals, carbonization tests were made on coals and coal blends from various States to determine their suitability for the production of metallurgical coke. The carbonizing properties of Bakerstown-bed coal from No. 23 mine, Coketon, Tucker County, W. Va.,[50] were determined by the Bureau of Mines-American Gas Association (BM-AGA) method. Blends containing 80 and 70 percent Pittsburgh-bed (Warden mine) coal were carbonized in the 18-inch retort at 800° C. Bakerstown coal ranks as a medium-volative coal containing 77.4 percent fixed carbon upon the dry, mineral-matter-free basis, 21.6 percent volatile matter, 5.7 percent ash, 1.0 percent sulfur, and a heating value of 14,470 B.t.u. per pound upon the as-carbonized basis. The ratio of fixed carbon to volatile matter was 3:1, and the softening temperature of the ash was 2,450° F. These properties fulfill the general specifications for coking coals. Microscopic analyses showed that the composition of Bakerstown coal approximates that of an average bright coal. The column sample taken at the point in the mine where the carbonizing sample was obtained contained 91 percent bright coal. The yield of coke was high for a medium-volatile coal; but because Bakerstown coal is high in that rank, all yields were considered normal. Results of physical tests of the coke indicated that it was exceedingly stable. Blending with Pittsburgh coal decreased the yield of coke and increased the yields of other carbonization products. The coke from the blends was not as stable, but it had good physical properties that compared favorably with those of coke from blends of Pocahontas and Pittsburgh coals. Bakerstown coal expanded 9.8 percent during carbonization at 950° C. when charged at a density of 55.5 pounds per cubic foot. It should be used with caution in byproduct ovens.

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[50] Davis, J. D., Reynolds, D. A. Sprunk, G. C., and Holmes, C. R., Carbonizing Properties and Petrographic Composition of Bakerstown-bed Coal from No. 23 mine, Coketon, Tucker County, W. Va., and the Effect of Blending This Coal with Pittsburgh-bed (Warden mine) Coal: Bureau of Mines Tech. Paper 644, 1942, 46 pp.

The carbonizing properties and petrographic composition of No. 2-bed coal from Bartoy mine and No. 5-bed coal from Wilkeson-Miller mine[51] were determined. The coal is 98 percent bright and contains only a trace of fusain. The washed sample contained 11.4 percent ash, 2.2 percent moisture, and 0.6 percent sulfur upon the as-carbonized basis and 68.4 percent fixed carbon upon the dry, mineral-matter-free basis. The heating value was 15,185 B.t.u. per pound upon the moist, mineral-matter-free basis. No. 2 therefore ranks as a high-volatile A coal and is very high in that rank. Except for its ash content, the coal fulfills the requirements of a coking coal. Its friability is 88.0 percent. The agglutinating index (7.6 for the 15:1 ratio of silicon carbide to coal) is high, and the plasticity is low for high-volatile A coal. Like the No. 2 coal, virtually all the No. 5 coal is bright, with only a trace of fusian. It contains 59.7 percent fixed carbon upon the dry, mineral-matter-free basis and had a heating value of 15,095 B.t.u. per pound upon the moist, mineral-matter-free basis. The coal therefore ranks as a high-volatile A coal, although it is low in that rank. It contained 1.7 percent moisture, 6.3 percent ash, and 0.6 percent sulfur as carbonized. The friability index was 71.3 agglutinating index 5.8, and plasticity index 294 dial divisions a minute. Except for the yield of ammonium sulfate, which was high for both No. 2 and No. 5 coals, the yields were normal for the ranks of the respective coals. Physical tests showed that No. 2 coke was stronger and that No. 5 coal yields weaker coke when generally is obtained from high-volatile A coals.

The composition and carbonizing properties of high-volatile A Taggart-bed coal from Nos. 30 and 31 mines, Lynch, Harlan County, Ky., were investigated.[52] This coal ranks as a high-volatile A bituminous coal. It contained 33.8 percent volatile matter, 2.5 percent moisture, 5.4 percent ash 7.9 percent oxygen, and 0.8 percent sulfur, as carbonized. These properties fulfill the general chemical specifications for gas and coking coals. These coals usually contain appreciable percentages of splinty constituents. The friability index was 27.0, whereas fluidity was very high (1,125 dial divisions per minute) and the temperature range of plasticity (54° C.) was short. The coke was more resistant to breakage by impact but was more abradable. Blending this coal with Pocahontas No. 3- and No. 4-bed coals increased the yield of coke and decreased the yields of gas, tar, and light oil. The coking power does not deteriorate rapidly under ordinary storage conditions.

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[51] Davis, J. D., Reynolds, D. A., Sprunk, G. C., Holmes, C. R., and McCartney, J. T., Carbonizing Properties and Petrographic Composition of No. 2-bed Coal from Bartoy mine and No. 5-bed Coal from Wilkeson-Miller mine, Wilkeson, Pierce County, Washington: Burea of Mines Tech. Paper 649, 1942, 48 pp.

[52] Davis J. D., Reynolds, D. A., Sprunk, G. C., and Holmes, C. R., Carbonizing Properties and Petrographic Composition of Taggart-bed Coal from Mines 30 and 31, Lynch, Harlan County, Ky., and the Effect of Blending this Coal with Pocahontas No. 3- and No. 4-bed Coals: Bureau of Mines Tech. Paper 650, 1943, 45 pp.

Carbonization tests were made on a sample of McAlester-bed coal from the No. 10 mine at Dow, Pittsburg County, Okla.[53] This coal is high-volatile A. Blends were made with low-volatile Hartshorne coal from mine 17 at Bokoshe, LeFlore County, Okla. The ash and sulfur contents of McAlester coal are well within the limits set by the American Society for Testing Materials for coke- and gas-making coals. When high-sulfur Hartshorne coal is blended with low-sulfur McAlester coal, the sulfur content of the coke remains well within the limits set by the Society. It is believed that the cokes would give some trouble from clinkering of the ash if used in a water-gas set or for domestic heating. On the whole, the yields of products from the coal were satisfactory either as 100-percent McAlester coal or in a blend. Physical tests showed the coke to be medium-grained, small-size, and highly fissured with resulting considerable degradation in size in shatter and tumbler experiments. Blending with Hartshorne or other nearby low-volatile coal improved the physical characteristics significantly. Coking power is lost rapidly, owing to oxidation, and the coal must be stored with care.

For the purpose of determining the behavior and usefulness of high-sulfur, high-volatile coking coal, such as that mined in Kansas,[54] in the manufacture of coke and subsequent generation of water gas, a coal from the Bevier bed, Kansas, was used in a series of tests. The coking properties of this fuel are such that it can be coked in slot-type ovens without damage to the oven through swelling during carbonization. One of the important factors limiting the use of this coal is the nature and characteristics of its ash. The ash has a very low softening and liquefaction temperature. Because the ash is high in both Fe_2O_3 and CaO, it produces severe grate clinker to such an extent as to interfere seriously with operation of the water-gas machine. Viscosity measurements on coal-ash slags of similar composition showed the slag to be exceptionally fluid. The sulfur content of the coal is indicated as being important when the ash also contains considerable CaO as calcite, because of the possible formation of calcium sulfate with correspondingly highly fluid slag. Coke can be made from this fuel in either the Curran-Knowles or Koppers ovens. Water gas was made from the coke made in Curran-Knowles ovens, and, largely because of the properties of the coke-ash, the coke is not recommended for use in making water gas in generators having mechanical grates.

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[53] Davis, J. D., and Reynolds, D. A., Carbonizing Properties of McAlester Bed Coal from Dow No. 10 Mine, Dow, Pittsburg County, Oklahoma: Okla. Geol. Sur. Min. Rept. No. 15, 1942, 13 pp.

[54] Odell, W. W., Carbonization of Bevier-bed Coal from Kansas and Production of Blue Water Gas from the Resulting Coke: Bureau of Mines Rept. of Investigations 3671, 1942, 21 pp.

Comparative Yields of Products from Carbonization Tests

The yields of light oil, tar, and constituents from carbonization tests at 800°, 900°, and 1,000° C. on coals from 32 beds were compared.55/ This paper points out the effect of variation of carbonization temperature on yields of certain products now very important in the prosecution of the war. The origin and analyses are given, as well as the yields of light oil, benzene, toluene, tar, and tar acids, in gallons per ton of coal carbonized; yields of naphthalene, anthracene, and ammonium sulfate are given in pounds per ton. It is indicated that, in general, increasing carbonizing temperature increases the yields of light oil, benzene, naphthalene, and anthracene; at the same time the yields of toluene, tar, tar acids, and ammonium sulfate decline. The effect of decreasing rank is to increase, on the average, the yields of light oil, benzene, toluene, tar, tar acids, and ammonium sulfate. The naphthalene and anthracene yields usually show no particular trend with decreasing rank, except when considered at the different carbonizing temperatures. Naphthalene increases with decreasing rank at 900° and 1,000° C., but at 800° C. the highest yield is obtained from the low-volatile coals. At 1,000° C., anthracene increases with decreasing rank, whereas at 800° and 900° C. the medium-volatile coals yield the least.

The method now in general use for analyzing light oil for benzene has been found satisfactory for light oils from coals carbonized at 500°, 600°, and 700° C. but does not give accurate, reproducible results for oils from the 800° C. tests. An improved method of determining benzene in medium-temperature light oils has been developed.56/

55/ Holmes, C. R., Wilson, J. E., and Davis, J. D., Comparative Yields of Light Oil, Tar, and Constituents from Carbonization Tests at 800 900°, and 1,000° C: Bureau of Mines Rept. of Investigations 3695, 1943, 12 pp.

56/ Rockenbach, L. P., and Reynolds, D. A., Improved Method of Determining Benzene in Medium-temperature Light Oils: Bureau of Mines Rept. of Investigations 3619, 1943, 5 pp.

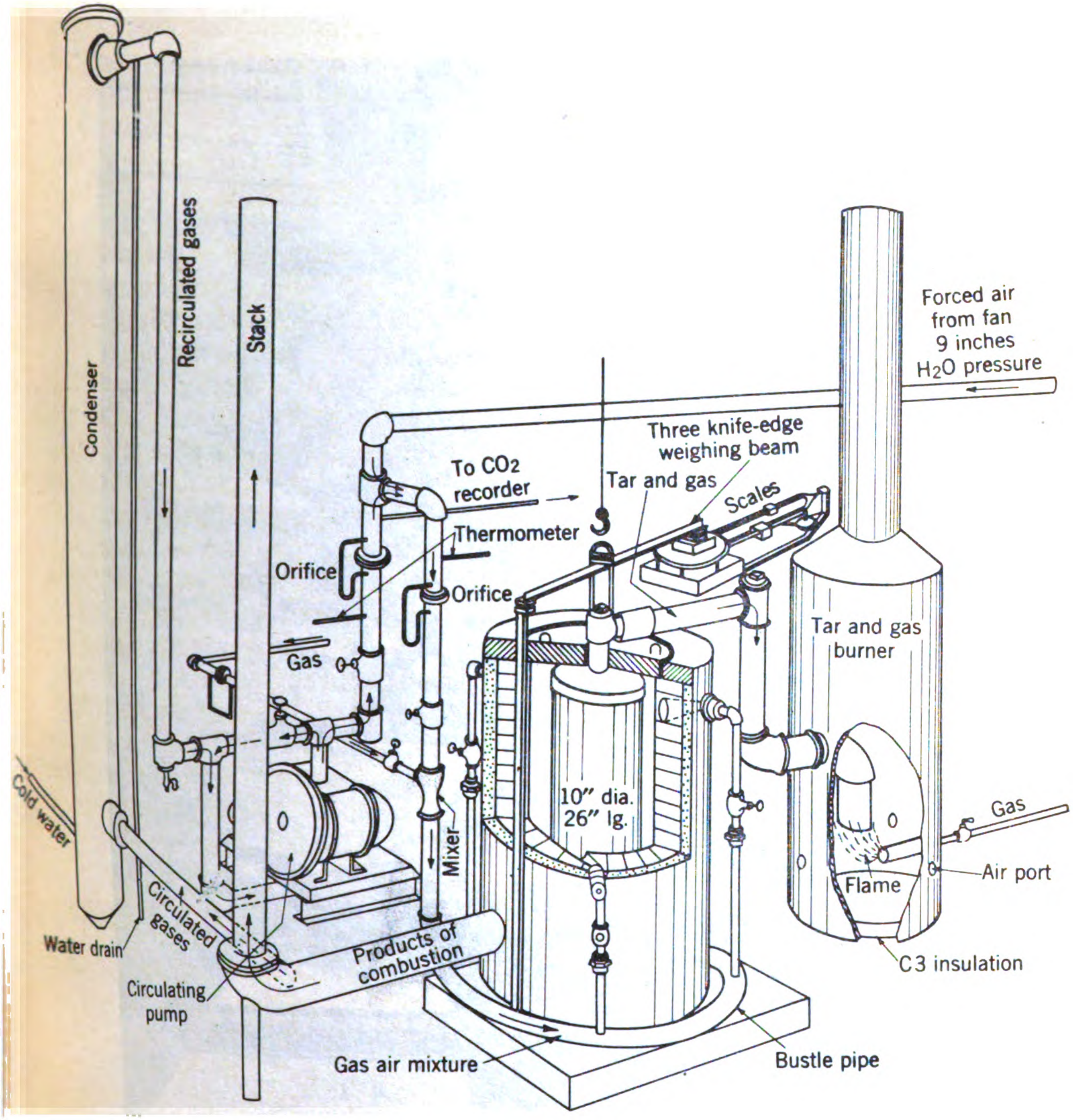

Figure 29.- Gas-heated 50-pound carbonizing unit, 10-inch circular retort.

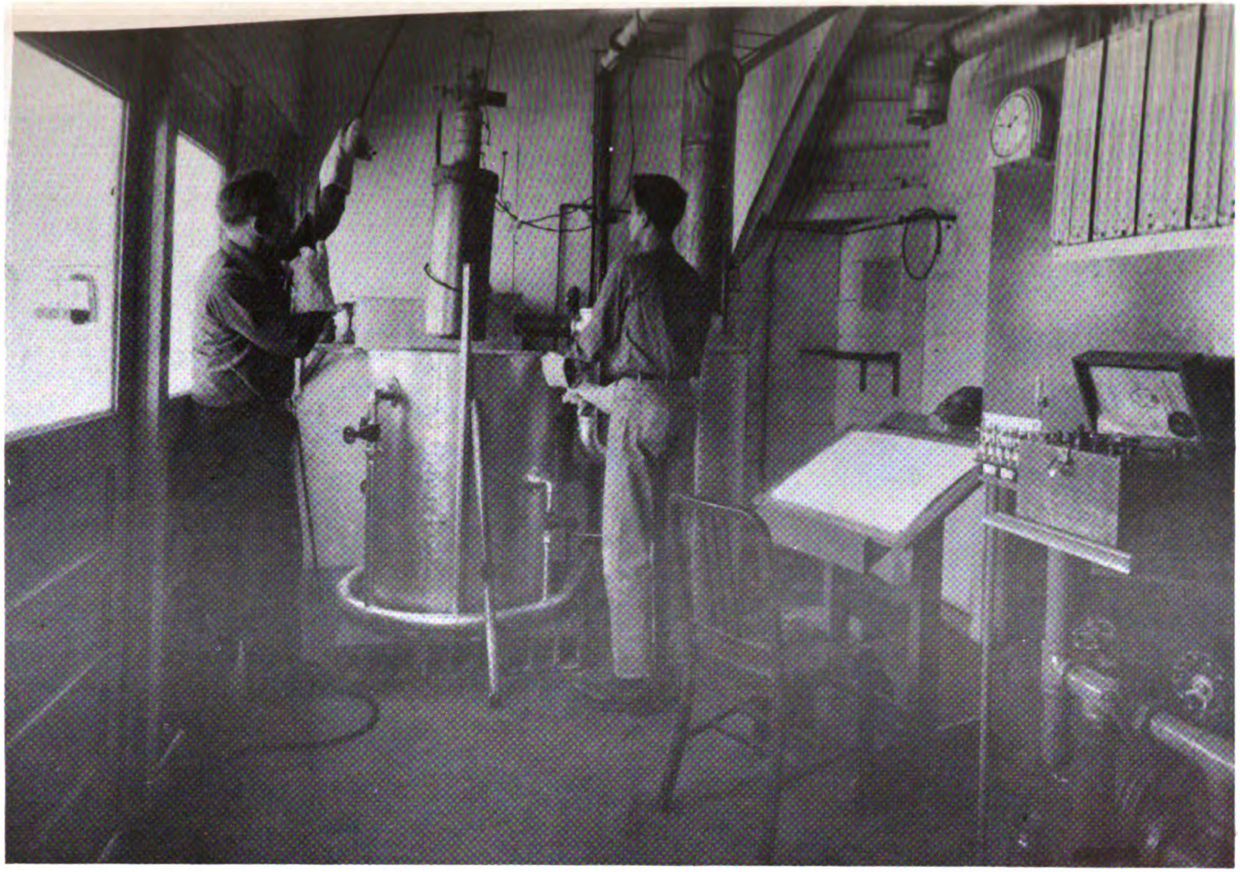

Figure 30.- Modified BM-AGA carbonizing unit, 10-inch diameter, 50-pound capacity.

Original from THE OHIO STATE UNIVERSITY

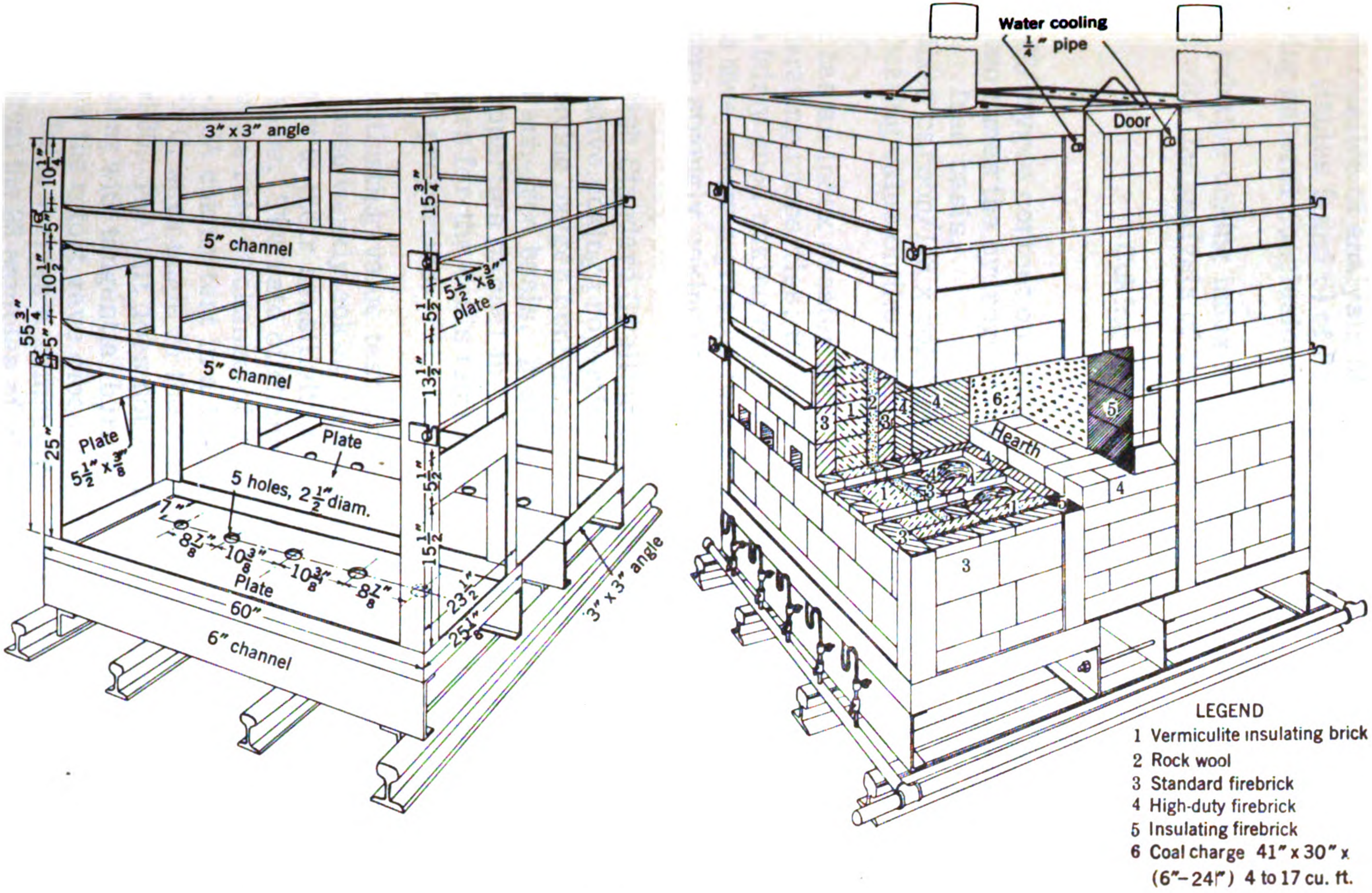

Figure 31,- Experimental coke oven, 6- to 24-inch coking chamber.

Laboratory Tests of Coking Properties of Western Coals

A correlation of analysis of coal, coking indexes, and experimental coking tests (tables 5 and 6) of 23 representative western coals supports the following general conclusions:

The relative coking index of these high-oxygen western coals was correlated with the analysis of the coal by the following formula:

$$\text{Coking index} = \frac{a + b + c + d}{5}$$

a = 22/oxygen content on moisture- and ash-free basis, percent.
b = two times the hydrogen/oxygen content on moisture- and ash-free basis.
c = fixed carbon/1.3 x volatile matter.
d = heating value on the moist, ash-free basis/13,600.

If the coal has an index greater than 1, it is likely that it has some coking or agglomerating properties; if the index is more than 1.10, the coal probably is a fairly good coking coal. All the nonfusing coals with weak coking properties have indexes greater than 1; as the index increases, the coals become more strongly coking or more plastic.

The British Standard Swelling test appears to be a good method for estimating relative coking properties of coal, especially for testing weakly coking coals having oxygen contents between 7 and 11 percent on the moisture- and ash-free basis. It should have practical value for classifying coking properties of coal in different parts of a mine. Table 6 gives swelling numbers for the coals tested and compares other small laboratory tests for coking properties.

The agglutinating-value test did not show close correlation with coking properties of these weakly coking high-oxygen western coals. This may be due in large part to their sensitivity to oxidation, which greatly affects the agglutinating value. The rate of change of agglutinating value is considerably faster than the rate of change of coking properties, as indicated by a modified BM-AGA coking test in a 10-inch circular retort. Coking tests at 1,000° and 900° C. were made in the gas-fired equipment illustrated in figures 29 and 30. The unit does not measure or recover byproducts. The method of heating with tangential burners and products of combustion circulating around the retort gave close control of furnace atmosphere and temperature. Table 7 gives a summary of certain physical properties of cokes made from the 23 samples of Western coals. An experimental 14-inch coke oven, illustrated in figure 31, will be used to determine coking properties of coal under conditions simulating those obtained in commercial byproduct ovens.

TABLE 5. - Analyses of coals, as carbonized

Coal No.	Mine	County	State	Analyses, percent									B.t.u.
				Proximate				Ultimate					
				Moisture	V.M.	F.C.	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
136-1	McCann	Pitkin	Colo.	1.9	31.7	58.8	7.6	5.4	78.4	1.8	6.3	0.5	14010
152-2	Frederick	Las Animas	do.	2.2	32.3	55.1	10.4	5.3	75.1	1.6	7.1	.5	13390
147-1	Morley	Las Animas	do.	1.5	32.9	51.1	14.5	5.0	71.3	1.4	7.1	.7	12720
132-1	CFI - 90-10	-	-	11.0	30.6	48.8	9.6	5.7	67.5	1.4	15.3	.5	12060
148-1	Boncarbo	Las Animas	Colo.	6.5	32.1	48.6	12.8	9.3	67.8	1.5	12.1	.5	12140
146-1	Dawson #6	Colfax	N. Mex.	3.1	35.0	44.2	17.7	5.2	65.8	1.2	9.5	.6	11860
155-1	Sunnyside	Carbon	Utah	5.8	38.4	50.3	5.5	5.8	73.1	1.5	12.9	1.2	13130
144-1	Koehler #1 and 2	Colfax	N. Mex.	2.1	35.5	48.2	14.2	5.1	69.6	1.3	9.2	.6	12410
143-3	Columbia	Carbon	Utah	5.3	38.0	51.5	5.2	5.7	73.1	1.5	13.7	.8	13130
149-1	Daisy	Las Animas	Colo.	2.8	33.7	47.0	16.5	5.0	66.1	1.2	10.6	.6	11730
150-1	Rouse	Huerfano	do.	3.1	35.0	44.9	17.0	5.1	65.2	1.2	10.7	.8	11660
138-1	Oliver	Gunnison	do.	5.7	38.7	50.5	5.1	5.8	72.6	1.5	14.4	.6	12990
145-1	Lamb	Sante Fe	N. Mex.	3.1	35.8	51.4	9.7	5.2	71.8	1.2	11.2	.9	12750
133-1	Hawk's Nest	Gunnison	Colo.	6.8	37.7	50.8	4.7	5.8	71.9	1.6	15.1	.9	12800
137-1	Somerset	Gunnison	do.	6.3	37.9	48.4	7.4	5.8	70.5	1.4	14.5	.4	12570
156-1	Gomer #5	Lincoln	Wyo.	2.8	38.6	53.9	4.7	5.6	76.4	1.3	11.0	1.0	13610
140-1	Crested Butte	Gunnison	Colo.	4.6	36.6	52.3	6.5	5.6	73.3	1.6	12.6	.4	13000
158-1	Standard	Carbon	Utah	3.1	42.9	47.4	6.6	5.9	73.6	1.3	11.7	.9	13330
159-1	Deer Creek	Emery	do.	5.0	43.7	45.9	5.4	6.0	72.7	1.4	14.0	.5	13180
135-1	New Castle	Garfield	Colo.	3.8	40.2	51.2	4.8	5.7	74.0	1.7	13.3	.5	13170
151-1	Robinson #4	Huerfano	do.	4.5	35.5	47.5	12.5	5.1	67.6	1.2	12.9	.7	11940
153-1	Moffat #1 and 2	Routt	do.	8.5	38.5	48.5	4.5	5.8	69.6	1.7	17.3	1.1	12230
134-1	South Canon	Garfield	do.	7.5	38.0	51.0	3.5	5.8	70.5	1.8	17.9	.5	12470

TABLE 6. - Plastic properties and coking indexes of coals carbonized

Coal No. (1)	B.S.S.T. 1/ (2)	Agglutinating value (3)	Plastic index (4)	Calculated coking index (5)	Softening point, °C. (6)	Maximum plasticity (7)	Combined coking index 2/ (8)
136-1	8.5	8.4	5.0	1.80	364	410	8.7
152-2	8.7	8.3	5.0	1.60	366	401	8.1
147-1	7.6	4.6	3.9	1.42	365	416	6.0
132-1	6.5	4.4	3.9	1.39	369	418	5.7
148-1	6.7	5.7	4.1	1.29	373	422	5.8
146-1	3.5	4.3	3.8	1.21	364	426	4.4
155-1	4.75	3.9	3.5	1.18	382	430	4.4
144-1	4.0	3.5	3.6	1.21	364	436	4.2
143-3	4.5	3.0	3.1	1.09	380	433	3.8
149-1	2.5	3.4	2.8	1.10	380	444	3.4
150-1	1.6	2.4	2.0	1.08	380	443	2.7
138-1	3.5	1.9	1.8	1.04	390	435	2.9
145-1	2.5	2.0	1.4	1.10	386	440	2.7
133-1	3.25	-1	2.3	1.06	380	430	2.6
137-1	3.0	1.3	1.3	1.06	386	435	2.6
156-1	1.0	2.2	1.5	1.15	377	431	2.5
140-1	2.2	-1	2.0	1.10	384	436	2.4
158-1	2.9	-1	-0.4	.99	380	432	1.7
159-1	2.6	-1	-0.6	1.01	382	432	1.6
135-1	1.5	0	.4	1.02	386	429	1.5
151-1	1.0	0	-0.5	1.02	391	428	1.2
153-1	1.5	0	-0.5	.96	393	430	1.2
134-1	1.5	0	+1.2	.92	405	432	.9

1/ British Standard Swelling Test, average swelling number of 8 buttons.

2/ Average of British Standard Swelling Number, the agglutinating value, the plastic index, and the calculated coking index.

TABLE 7. - Coke yield and properties of cokes carbonized in 10-inch modified BM-AGA retort at 1,000° C.

Coal No. (1)	Yield, per-cent (2)	Average size, inches (3)	Plus 1.06-inch, percent (4)	Size stability percent1/ (5)	Apparent specific gravity (6)	Cell space, percent (7)	Coke-strength factor2/ (8)	Net resultant coke factor3 (9)
136-1	70.2	1.602	82.6	51.4	0.78	60.5	108	0.56
152-2	69.5	2.012	90.4	41.2	.87	56.7	111	.56
147-1	71.0	1.999	91.6	43.0	.85	56.6	115	.58
132-1	66.0	1.738	87.9	43.2	.81	59.1	99	.46
148-1	65.3	2.029	93.3	42.7	.86	57.0	116	.52
146-1	67.0	2.198	88.2	35.7	.87	56.3	105	.47
155-1	61.0	1.524	78.7	45.8	.75	59.5	86	.41
144-1	66.7	1.843	88.8	43.5	.89	53.1	106	.49
143-3	61.4	1.387	70.1	46.1	.73	60.1	71	.38
149-1	67.8	2.233	90.5	39.2	.93	53.3	114	.54
150-1	66.8	2.215	89.2	38.1	.87	55.8	110	.50
138-1	61.0	1.281	59.3	42.0	-	-	59	.32
145-1	64.9	1.411	68.2	42.2	.78	58.3	67	.36
133-1	59.4	1.207	52.6	45.3	.73	59.2	54	.31
137-1	61.5	1.276	61.6	46.8	.71	61.6	68	.35
156-1	63.9	1.423	74.5	43.3	.81	55.2	74	.38
140-1	63.4	1.419	72.3	44.8	.76	58.7	72	.39
158-1	57.3	1.180	55.1	35.0	.75	59.0	51	.22
159-1	55.8	1.219	57.9	36.7	.69	62.1	55	.24
135-1	61.0	1.154	51.4	42.1	.73		54	.28
151-1	64.6	.619	29.0	29.6	.86		33	.11
153-1	60.4	1.013	52.2	39.5	.93		53	.23
134-1	59.0	.639	32.2	37.3	.68		39	.14

1/ 100 x average size of tumbler resultant, in inches, / average size of tumbler charge, in inches.

2/ Modified coke-strength index for coke from 10-inch BM-AGA retort = cumulative percentage retained on 1.5-inch screen analysis x 0.284 + cumulative percentage retained on 1.06-inch screen analysis x 0.202 cumulative percentage retained on 0.265-inch tumbler test x 0.259 + cumulative percentage retained on 1.06-inch tumbler x 0.902 + (size stability) x 0.269. This is based upon method of L. D. Schmidt (Iron and Steel Engineer, vol. 18, No. 3, 1941, pp. 67-70).

3/ Net resultant coke factor = ash-free coke yield, percent, x average size stability / 10,000.

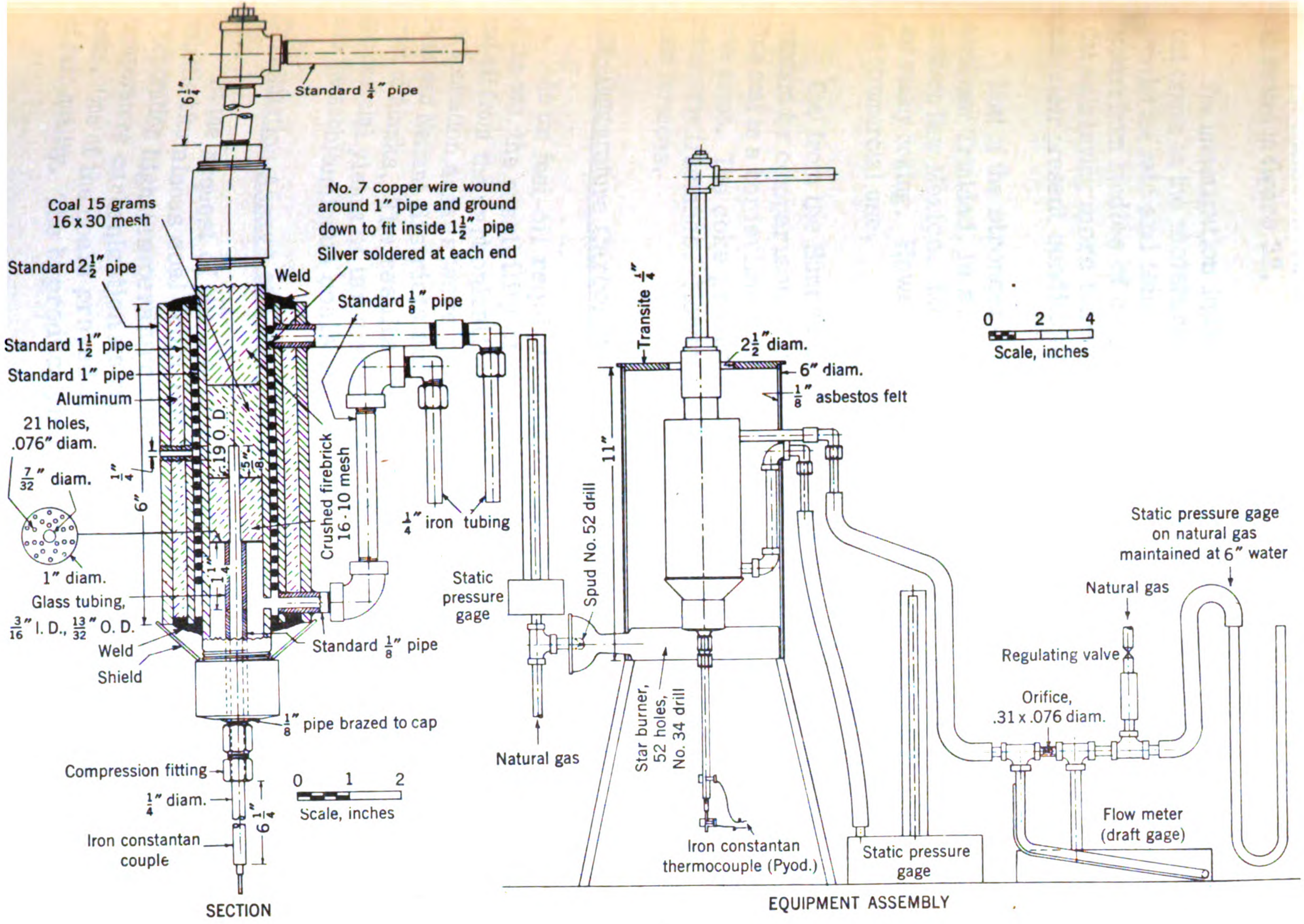

Figure 32.- Plastometer for high-oxygen coals.

The plastic index was determined by a device of the Foxwell type illustrated in figure 32.

The investigation indicated that any coal having less than 10.5 percent oxygen on the moisture- and ash-free basis can be made to coke, provided the rate and temperature of carbonization is high enough. It appears from studies of coal now coked in byproduct ovens at Provo, Utah, that coals having more than 10 percent oxygen will not make satisfactory coke under present conditions of commercial operation.

Most of the stronger-coking coals of the Rocky Mountain region are found near Trinidad, in southern Colorado, and in the Raton district of northern New Mexico. Most of the western slope coals are high in oxygen and weakly coking. However, a few beds in limited areas may be suitable for commercial use.

Coal from the Sunnyside district in Carbon County, Utah, is considered standard for comparison of coking properties of high-oxygen coking coals. This coal is a borderline coking coal for present commercial byproduct coke ovens. The coke produced is small and contains many lateral and transverse fractures. However, it is hard and is used successfully in blast furnaces.

Low-Temperature Carbonization Assays of Alaskan Coals

As the fuel-oil requirements of Alaska have increased greatly because of the war, the possibility of increasing the available supply by using tar and oil from the carbonization of coal was investigated. Low-temperature carbonization assays were made of three subbituminous coals of the Broad Pass and Nenana districts and two bituminous coals of the Matanuska district of Alaska. The results showed that the bituminous coals will give commercial yields of tar and oil as high as 28 gallons per ton of coal, and the subbituminous coals will yield up to 16 gallons per ton.

Carbonization Assays of Peruvian Coals

At the request of the Peruvian government, two samples of high-volatile bituminous coal from Peru were tested by the United States Steel Corporation high-temperature distillation test and the Fischer low-temperature carbonization assay to determine their suitability for making coke. One of the coals proved to be noncoking, and the other gave a coke of fair quality. The byproduct yields were normal for coals of their rank.

Better Coke Improves Pig-Iron Production

The highly mechanized character of modern warfare makes steel one of the most vital raw materials. The shortage of steel scrap in the United States is forcing the use of greater quantities of pig iron in steel manufacture, so that the rate of pig-iron output will continue to be the controlling factor in steel production. At the same time, the construction of new blast furnaces is limited by both time and the amount of strategic material available. Under such circumstances, every effort must be made to attain and then maintain maximum pig-iron output with equipment now in use.

When forcing a blast furnace to the ultimate in production, the highest standards for quality and uniformity of the coke must be maintained. In view of these facts, the Bureau of Mines, in cooperation with the Office of the Solid Fuels Coordinator for War, is surveying the coke industry to stud the various steps in producing coke of high quality and greater uniformity.[57] The engineers conducting the survey are visiting key men in coke-oven and blast-furnace organizations to determine, first, the major and most common problems in coke production and use, and, second, the best and quickest methods for solving them. It is the purpose of the survey and subsequent reports to facilitate such exchange of information.[58]

As an outgrowth of the survey, it was soon revealed that many operators could be helped by cooperation with various Government agencies, particularly to procure suitable coals, minor additions to equipment facilities, testing facilities for certain properties of coal or coke, and advice concerning the operation of various types of equipment. Many coke plants have improved the quality of their blast-furnace coke by increasing the proportion of low-volatile coal in the blend charged to the ovens. To aid operators in selecting low- and medium-volatile coals for blending with their high-volatile coals for greater coke strength, the data shown in table and figure 33 were prepared. On the average for the many different blend shown, the use of 20 percent by weight of low- or medium-volatile coal increases the strength of coke by about 9 percent. The strength of coke produced from one high-volatile coal was increased by 46 percent by blending it with 20 percent of low-volatile coal.

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[57] Fieldner, A. C., Better Coke for More Pig-iron Production: Blast Furnace and Steel Plant, vol. 30, No. 11, Nov. 1942, pp. 1279-1281, 1306-1307.

[58] Schmidt, L. D., Schroeder, W. C., and Fieldner, A. C., Increased Pig-iron Output Through improved Coke: Bureau of Mines Rept. of Investigations 3711, 1943, 58 pp.

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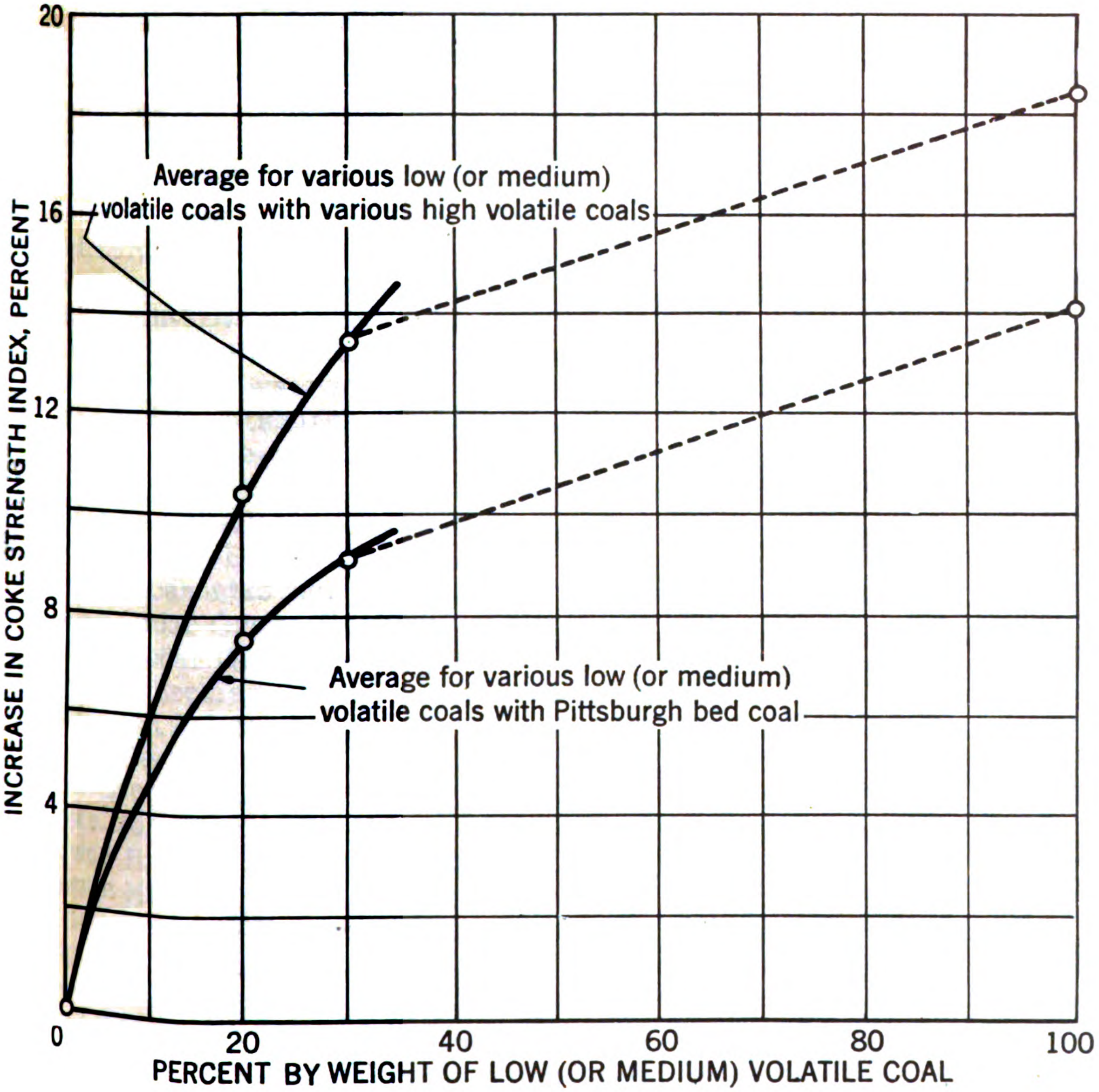

Figure 33.- Increasing the strength of coke by blending low- (or medium-) volatile coals with high-volatile coals.

TABLE 8. - Strength indexes of cokes made from various blends of coals

[illegible][1]	Coal Beds	Low- (or Medium-) Volatile Coal in Blend, Percent 0	20	30	100
-60	Pittsburgh-Upper Kittanning	91.4	97.5	98.9	105.0
-61	do.[2]	91.4	96.9	95.8	104.7
-47	Pittsburgh-Lower Kittanning	91.4	97.1	99.7	99.2
-43	do.[2]	91.4	97.4	99.6	100.1
-57	Pittsburgh-Pocahontas No. 4	91.4	97.2	99.6	99.7
-66	Pittsburgh-Pocahontas No. 3	91.4	95.3	97.8	97.8
-41	Pittsburgh-Beckley	91.4	97.1	103.0	104.0
-28	Pittsburgh-Sewell	91.4	103.6	-	106.7
-41	Pittsburgh-Beckley	80.9	91.5	95.3	104.0
-23	Pittsburgh-Pocahontas No. 4	94.4	98.5	-	99.1
-63	Pittsburgh-Lower Banner	91.4	94.7	99.3	102.7
-60	Pittsburgh-Lower Freeport	91.4	98.3	99.1	109.1
-4	Pittsburgh-Davis	91.4	98.8	-	109.9
-34	Pittsburgh-Bakerstown	91.4	101.6	102.4	109.1
	Average for Pittsburgh-bed blends	90.86	97.54	99.14	103.65
	Increase in coke-strength index, percent	0	7.4	9.1	14.1
-41	Pond Creek-Beckley	96.4	100.2	101.0	104.0
-41	Upper Banner-Beckley	94.0	97.9	101.1	104.0
-41	Indiana No. 4-Beckley	78.0	93.4	98.7	104.0
-23	Alma-Pocahontas No. 4	89.6	99.1	95.3	99.1
-41	Upper Cedar Grove-Beckley	88.0	93.5	98.1	104.0
-41	Lower Cedar Grove-Beckley	94.1	99.8	99.8	104.0
-41	Dorothy-Beckley	93.0	96.3	98.9	104.0
-41	Powellton A-Beckley	92.9	97.7	100.1	104.0
-41	Eagle-Beckley	92.6	98.9	100.1	104.0
-66	Powellton-Pocahontas No. 3	94.3	97.9	98.5	97.8
-57	Powellton-Pocahontas No. 4	94.3	99.1	100.0	99.7
-66	Lower Hignite-Pocahontas No. 3	73.8	90.4	93.0	97.8
-57	Lower Hignite-Pocahontas No. 4	73.8	89.1	93.9	99.7
-23	Miller's Creek-Pocahontas No. 4	81.5	78.7	93.8	99.1
-41	High Splint-Beckley	80.5	92.9	95.2	104.0
-66	Bell No. 1-Pocahontas No. 3	91.3	96.8	95.6	97.8
-57	Bell No. 1-Pocahontas No. 4	91.3	97.7	98.0	99.7
-69	Henryetta-Lower Hartshorne	78.0	95.7	99.2	-
-70	Henryetta-Upper Hartshorne	78.0	99.3	98.6	-
-74	McAlester-Hartshorne	61.8	89.9	94.2	-
-55	Alma-Sewell	89.6	95.9	100.2	106.2
-27	Upper Banner-Sewell	94.0	97.9	103.2	109.4
Average (excluding Pittsburgh bed)		86.40	95.37	98.02	102.23
Increase in coke-strength index, percent		0	10.4	13.4	18.3
Grand average (including Pittsburgh bed)		88.13	96.21	98.46	102.78
Increase in coke-strength index, percent		0	9.2	11.7	16.[illegible]

[1] The first number represents the high-volatile coal; the second represents blending coal. [2] Washed coal.

The following problems definitely limit the present rate of iron production and are most common to the companies in obtaining maximum production of the best quality of coke for maximum output in existing furnaces: (1) Limited availability of preferred coking coals; (2) shortage of ships for transportation by water and increasing difficulty of obtaining adequate transportation by rail; (3) difficulties in obtaining new equipment, repairs, and replacements; (4) high an increasing ash and sulfur content of coal as mined in many fields; and (5) lack of uniformity of coke because of (a) variability of ash, sulfur, and moisture content, (b) variability and inadequacy of physical structure, size, and strength, and (c) variability in the bulk density of the coke-oven charge, coking temperature, coking time, techniq of quenching, and adequate coke-storage space. Suggestions are made for solving each of these problems.

Plasticity and Swelling Properties of Coking Coals

The numerous test methods that have been devised for measuring the plastic and swelling properties of bituminous coking coals have been critically reviewed, and the test data have been interpreted in practical applications to the important problems involved in the coking process.59/ The present status of test methods for measuring the plastic, agglutinatin agglomerating, swelling, and expansion-pressure properties as well as other closely related characteristics justifies careful further investigatio It has been suggested that the latest proposed American and British metho for determining the agglutinating value and the Canadian method for estim ing the agglomerating value of coal have reached high degrees of perfecti Evidences of plasticity in heated coal have been demonstrated by many workers. Several different rheological60/ properties manifest themselve during the process of converting coal into semicoke, although it is not always possible to interpret the observed phenomena clearly in rheologica terms. Test methods for measuring the plastic, agglutinating, agglomera ing, and swelling properties of bituminous coals have been classified and discussed according to general test principles used for their determinati Wider use of absolute methods of measuring plasticity of coal should be encouraged. The elaborate apparatus and precise technique required hav militated against the adoption of such methods as routine tests in most laboratories. Direct observation-test methods often afford valuable perceptions of the phenomenon associated with the conversion of coal into semicoke. Macroscopic and microscopic observations of heated coal giv useful information for interpretating the coking process. Absorption and andadsorption of reagents such as pyridine at room temperatures by coa

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59/ Brewer, R. E., Plastic and Swelling Properties of Bituminous Cokin Coals: Bureau of Mines Bull. 445, 1942, 200 pp.

60/ Rheology is the science treating of the deformation and flow of matt

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of different rank appear to be related to their coking properties. Laboratory coking tests of coal with an inert material (agglutinating tests) and of coal alone (agglomerating tests) have been used widely. Such tests give data that aid in classifying coals for various purposes, although these tests have definitely limited application for certain types of coals. Larger-scale box and muffle tests are more directly applicable to coke-plant problems.

The extensively used dilatometer and penetrometer test methods differ mainly in the area and weight of that portion of the apparatus that bears on the coal charge. These methods give a good measure of the presoftening (initial-contraction) and fusion (initial-expansion or initial-penetration) temperatures. Gas-flow test methods have been used widely but have lost favor in recent years because test conditions that will allow accurate measurement of characteristic temperatures and corresponding pressures usually cannot be maintained. In the vertical-tube type of test, the light oil and tar are refluxed and fall back upon the charge, thus partly or completely sealing it. The temperature of maximum resistance to gas flow is actually the temperature at which plasticity of the coal ceases, and not the temperature of maximum plasticity as has often been assumed.

Extrusion tests show only whether or not the coal becomes plastic enough to flow during coke formation and do not measure relative plasticity at different periods. Laboratory constant-pressure tests to determine the amount of expansion (and/or contraction) of a heated coal are in reality modified swelling tests. The so-called "constant-volume" test methods, which usually allow the coal charge to expand the limited amount considered safe for industrial coke ovens, before the swelling pressure developed by the heated charge is measured, more nearly simulate coke-plant conditions. The direct application of test results to plant practice is governed by how closely the conditions chosen in the given test procedure actually simulate those prevailing in the coke oven. The larger-scale swelling-test apparatus or small experimental test ovens overcome the disadvantage of using very small coal charges.

Measurements of the distortion of coke-oven walls under known applied pressures have proved useful in designing commercial ovens. The recent American trend toward large test units and large-scale installations using two-sided heating appears most promising. The carbonization of poorly coking coals under high applied pressure to improve the quality of coke offers possibilities for the successful use of low-grade coking coals and lignites.

The chemistry of coking and relationships of plasticity and swelling-pressure data to the different amounts of gas evolved over certain ranges of temperature are discussed with reference to coke-oven and coal-gas-plant operations. The close relationship between characteristic temperatures of plasticity and initial decomposition of coal was pointed out. Special treatments, such as preheating, different rates of heating, pressure, hydrogenation, and methods for reducing the swelling pressure of coal have been reviewed.

HYDROGENATION AND LIQUEFACTION

Effect of Petrographic Composition and Rank of Coal

The petrographic and chemical data on the effect of rank and type o coal on its hydrogenation characteristics, obtained by the analysis and hydrogenation in small autoclaves of a large number of samples from mos of the important coal beds of the United States, have been presented.[61] Petrographic examination has been found useful for predicting the residu actually inert to continuous hydrogenation. The criteria to be used in determining rank (that is, whether the coal is anthracitic, bituminous, sub bituminous, or lignitic) and type (that is, whether the coal is bright, semi splint, splint, cannel, or boghead) are discussed. The petrographic constituents of coal (anthraxylon or vitrain, attritus, fusain, spores, and resi are described and illustrated, and these compositions of the various types of coal are specified.

Chemical methods of classifying coals into types and formulas, bas upon the proximate and ultimate analyses, are presented. Outstanding re sults indicate that bright coals containing less than 89 percent carbon hy genate readily, whereas dull coals containing a large quantity of opaque matter yield relatively little oil. One hundred and ninety hydrogenation e periments were made on 129 samples that were either pure constituents coal or mixtures containing known proportions of constituents. Hydroge tion tests were conducted in small rotating autoclaves of about 1-liter capacity. In general, the conditions that proved more desirable in experi ments with subbituminous and lignitic coals as compared with higher-ran coals were higher pressures and lower temperatures. For coals contain less than about 82 percent carbon, the yield of carbon dioxide increases rapidly with decreasing rank of the coal. The increased elimination of oxygen as carbon dioxide accounts for the fact that low-rank coals do not require much more hydrogen than do high-volatile bituminous coals.

A study of splint coals containing appreciable quantities of opaque matter shows that 40 to 80 percent of the opaque attritus liquefies, the degree of liquefaction being roughly proportional to the opacity. Hydrogenation of hand-picked fusains indicates that 10 to 55 percent of the fusain will liquefy upon hydrogenation. Spores, resins, and oil algae that occur in cannel coals in appreciable quantity are liquefied readily under very mild hydrogenating conditions, possibly because of the greater percentage of saturated hydrocarbons. Data are not yet available to indicate whether the transition from low-volatile bituminous coal to anthracite is accompanied by a gradual or a relatively sharp change in liquefaction.

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[61] Fisher, C. H., Sprunk, G. C., Eisner, A., O'Donnell, H. J., Clarke, and Storch, H. H., Hydrogenation and Liquefaction of Coal. Part 2 Effect of Petrographic Composition and Rank of Coal: Bureau of Tech. Paper 642, 1942, 162 pp. Abstracted in Oil and Gas Jour., v 41, No. 37, 1943, pp. 40-47

Characterization of Assay Oils

The experience of research chemists attempting to isolate and determine the constituents of petroleum has shown that to analyze such hydrocarbon mixtures is very difficult. The products obtained by hydrogenation of coal are somewhat simpler than natural petroleum, but their analysis presents a task of similar proportions. A preliminary report discusses analyses of coal-hydrogenation oils.[92] The results indicate that separations into various types of hydrocarbons by solvent fractionation may be necessary before efficient fractionation by distillation will be possible. Density, refractive index (of fraction before and after extraction with 98 percent sulfuric acid), sulfuric acid solubility, and carbon and hydrogen content were determined for 100 fractions of oil. Between 50 and 80 percent of all of the oil fractions boiling below 200° C. and 20 to 50 percent of those boiling above 200° C. are insoluble in 98 percent sulfuric acid. They apparently consist in the main of naphthenic compounds such as alkylcyclopentanes, alkylcyclohexanes, and alkylbicyclodecanes (saturated alkylhydronaphthalenes). Large portions of branched hexanes, cyclopentane, methylcyclopentane, and cyclohexane are apparent in the 50° to 85° C. fractions. Other fractions contained branched-chain paraffins, benzene, toluene, xylenes, and reactive olefins that form peroxides upon distillation.

Chemistry of Coal-Hydrogenation Reactions

Numerous experiments in small autoclaves have shown the importance of hydrogen "carriers" in the primary liquefaction of coal. These carriers are hydroaromatic compounds that transfer hydrogen to fragments of the coal molecules when the latter are in the process of "cracking" because of thermal decomposition. The chief function of the catalyst and hydrogen at high pressure is to increase the rate of regeneration of these hydrogen carriers. Because of the importance of this hydrogen-transfer reaction in coal hydrogenation and because of the very scanty information available concerning such reactions, typical reactions with pure substances, such as the anthracene-hydroanthracenes combination, are now being studied.

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[92] Hirst, L. L., Eisner, A., Field, J. H., Cooper, H. M., Abernethy, R. F., and Storch, H. H., Hydrogenation and Liquefaction of Coal. Part 3. Characterization of Assay Oils: Bureau of Mines Tech. Paper 646, 1942, 27 pp.

Synthesis of Hydrocarbons from Water Gas

In 1928 to 1930, the Bureau of Mines developed an active iron-copper catalyst for the Fischer-Tropsch process of synthesis of higher hydrocarbons (gasoline, Diesel oil, and paraffin wax) from water gas. Because of lack of funds, this research was discontinued. In 1942 funds were appropriated by Congress for further experimental work on this process. About 6 months of experimental work on iron and cobalt catalysts has been completed in the six laboratory catalyst testing units. (See figs. 34 and 35.) Methods for the preparation and reactivation of iron catalysts have been developed. One iron catalyst has been in operation for three months and has shown no loss in activity. The iron catalysts yield a highly olefinic product and a larger proportion of solid paraffins than is obtained with the cobalt catalyst. A standard cobalt-thoria-kieselguhr catalyst such as is in use in industrial-scale plants in Germany has been in service for 5 months. With periodic scrubbing with hydrogen to remove wax, this catalyst has shown only little deterioration in activity. Cheaper methods of preparation of cobalt catalysts have been investigated, and a very promising method has been developed.

Research on Water-Gas Production

Interpretation of available data on the steam-carbon reaction corroborated the generally accepted conclusions that the primary products are carbon monoxide and hydrogen, and that carbon dioxide is formed subsequently by way of the water-gas reaction. It is probable that the rate of gasification of the carbon is controlled by the rate of reaction of the absorbed film of steam, and that a steam-saturation pressure exists above which the rate of gasification of a given carbon at constant temperature remains constant with increasing steam pressure. Apparatus has been installed to measure the gasification rate over a wide pressure range.

Inspection of English Coal-Hydrogenation Plant

In May 1943, during a six weeks' trip to England made at the suggest of a subcommittee of the Committee on Mines and Mining of the House of Representatives,[63] Dr. H. H. Storch, supervising chemist, Coal Liquefact

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[63] Hearings on "Production of Gasoline from Coal" before a subcommitt of the committee on mines and mining, House of Representatives, 77th Cong. 2d Sess., 1942. Statement of A. C. Fieldner, pp. 2-17, 30-31; statement of H. H. Storch, pp. 38-44.

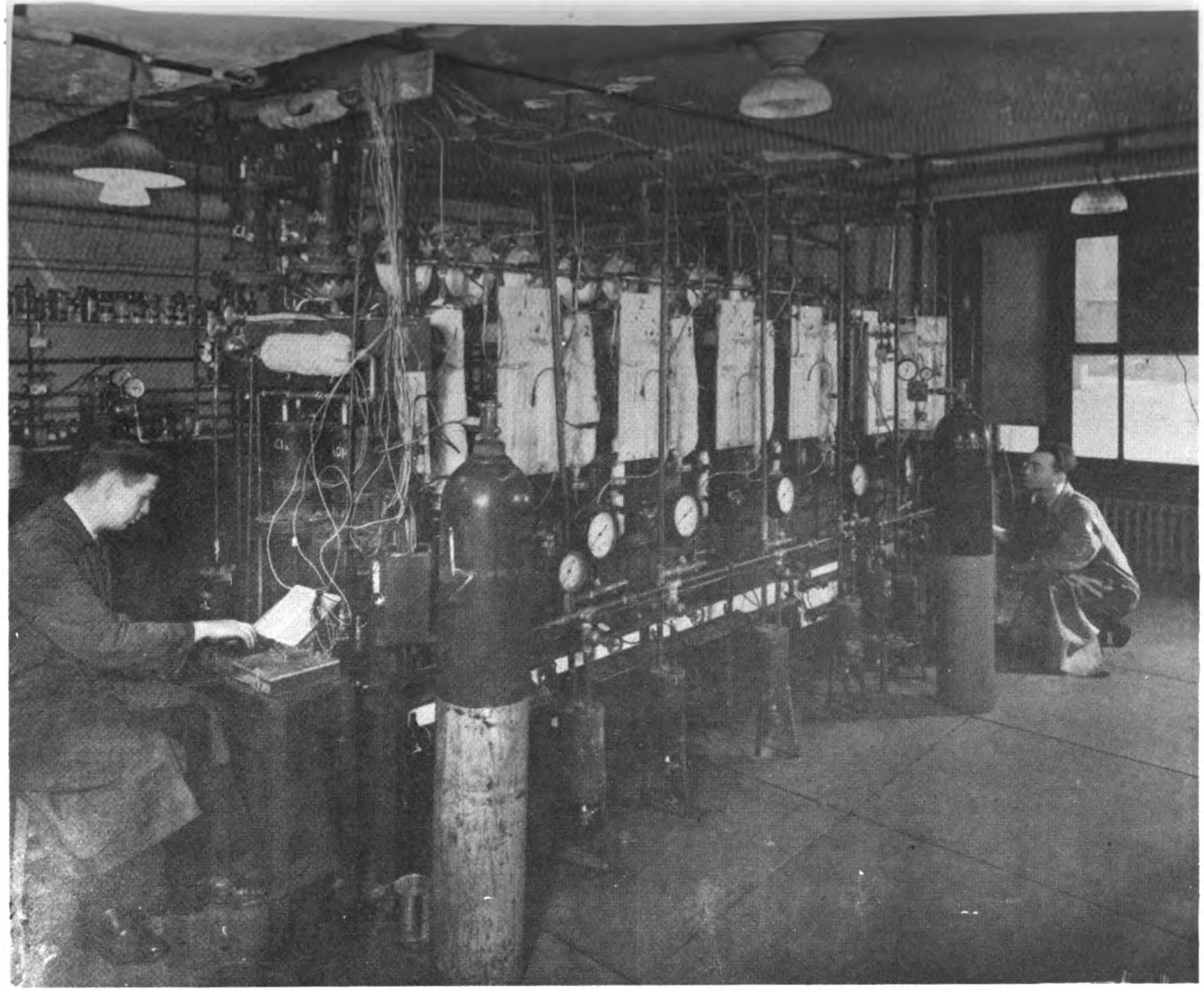

Figure 34.- Catalyst testing units. Front view.

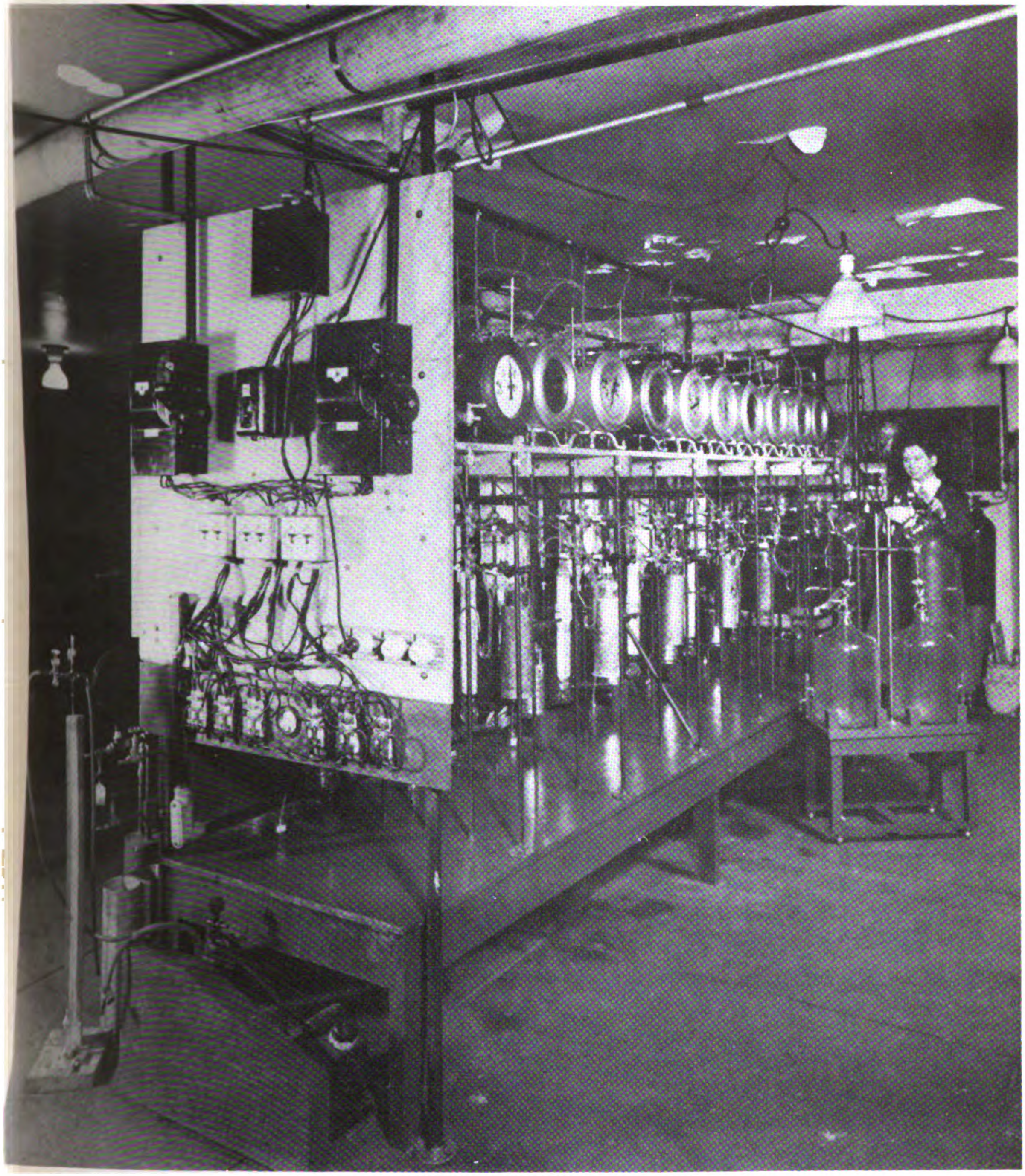

Figure 35.- Catalyst testing units. Rear view.

and Physical Chemistry Section, and Dr. W. C. Schroeder, assistant chief, Fuels and Explosives Service, obtained information concerning the design and operation of the industrial-size coal-hydrogenation plant at Billingham and details of laboratory research on the Fischer-Tropsch process conducted at the British Fuel Research Station. The information from Imperial Chemical Industries at Billingham shows that although the data obtained in experimental plants such as that now at Pittsburgh constitute a valuable index of the probable behavior of any particular coal, the results cannot be safely extrapolated to an operation of commercial size.

Synthetic-Rubber Production

Commercial production of synthetic rubber from coal, petroleum, and other materials in the United States became a reality in 1931 with the introduction of Duprene, a synthetic rubber made by polymerizing chloroprene.[64] Duprene was later improved and reintroduced as Neoprene. Since 1931, Thiokol, Buna S, Perbunan, Koroseal, Vistanex, Flamenol, Ameripol or Hycar, Chemigum, Butyl rubber, and Flexon have been announced and are produced commercially or are in the pilot-plant stage in this country. All of these compounds possess some of the physical properties of natural rubber, and in addition usually have some outstanding property not found in natural rubber that makes them superior for certain uses. Synthetic-rubber production in other countries began about 1934. Germany has announced the Buna rubbers Oppanol and Perduran. SKA, SKB, and Sovprene were developed in Russia. Ker came from Poland, Ekanite from Belgium, Mustone and Thionite from Japan, and Vulcaplas from England. The synthetic-rubber production program in the United States has been enlarged from actual production of 17,000 long tons in 1941 to a planned annual production of approximately 900,000 tons. According to the recommendations of the Baruch Committee, this will be made up of Neoprene (60,000 tons), Butyl rubber (132,000 tons), Buna S (845,000 tons), and Thiokol (60,000 tons). General information regarding the chemistry and physical properties of the synthetic rubbers produced commercially in the United States and other countries is catalogued for quick reference. Detailed descriptions of actual polymerization operations are not numerous in the literature on synthetic rubber technology.

Butadiene ($H_2C{=}CH{-}CH{=}CH_2$) is the most important of the raw materials for synthetic rubber under the present production program. The present commercial sources of butadiene are petroleum and petroleum gases, coal or coke and limestone, ethyl alcohol, and butylene glycol made by special fermentation of grain. It is produced by thermal cracking at high temperatures, direct catalytic dehydrogenation of butanes and butenes, from acetylene formed by pyrolysis of natural gas or by conversion to vinylacetylene and hydrogenation, or from alcohol manufactured from ethylene. Styrene ($C_6H_5CH=CH_2$) is manufactured by catalytically dehydrogenating ethyl benzene produced from benzene and ethylene or ethyl alcohol. Acrylonitrile ($H_2C=CHC=N$) is made by treating ethylene with hypochlorous acid to give ethylene chlorohydrin, which reacts with sodium cyanide to give hydracrylic nitrile, from which acrylonitrile is obtained by dehydration. Calcium carbide, made from lime and coke in a high-temperature electric furnace, gives acetylene when treated with water. Vinylacetylene, formed by polymerization of two molecules of acetylene, is treated with hydrochloric acid to give chloroprene ($H_2C=CH-CCl=Ch_2$). Isoprene and dimethylbutadiene are not now of any significance. Isobutylen ($H_2C=C-(CH_3)_3$) is the principal ingredient in the manufacture of Butyl rubber and also is an important material in the manufacture of high-octane gasoline. Alkali polysulfides used in Thiokol and the like are made from sulfur and alkali. The organic dihalides are made by halogenation of organic products. Vinyl chloride ($H_2C=CHCl$) is produced commercially by any of three methods: (1) Catalytic combination of acetylene and hydrogen chloride, (2) chlorination of ethylene to ethylene dichloride and partial dehydrohalogenation by treatment with alcoholic caustic, or (3) vapor-crackin ethylene dichloride.

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[64] Holliman, W. C., Synthetic Rubber, Its Production from Petroleum, Coal, and Other Materials: Bureau of Mines Inf. Circ. 7242, 1943, 36 pp.

Knowledge of the explosion hazards of combustible gases and liquids used in the manufacture of synthetic rubber is especially important at present, because they play an important role in the general program of national defense. A report has been made giving the results of numerous experiments to establish the limits of inflammability of butadiene-air mixtures to which various proportions of nitrogen and carbon dioxide wer added.[65] The limits of inflammability of butadiene in air were first deter mined and found to be 2.00 percent for the lower and 11.50 percent for the upper limit of inflammability. At least 19.6 volumes of nitrogen must be added to each volume of butadiene to make all mixtures with air noninflammable. Only 12.1 volumes of carbon dioxide were required to make all mixtures with air noninflammable. The results seem to confirm the conclusion that the effect of nitrogen and carbon dioxide in extinguishing flames is due largely to their heat capacity.

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[65] Jones, G. W., and Kennedy, R. E. Prevention of Butadiene-air Explosions by Addition of Nitrogen and Carbon Dioxide: Bureau of Mines Rept. of Investigations 3691, 1943, 11 pp.

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